Analysis of Surfaces from the LDEF A0114 - Phase II

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9/1/91 - 2/29/92

During the above mentioned reporting period, work has continued on profilometry measurements of eroded and corroded sample surfaces, optical transmission measurements, analysis of the pinhole camera and XPS analysis of some samples. The following papers have appeared or have been accepted for publication:

1. *Measurement of the Passive Attitude Control Performance of a Recovered Spacecraft,* J.C. Gregory, P.N. Peters, Journal of Guidance, Control, & Dynamics, 15, 1, 1992, p. 282-284

2. *The Interactions of Atmospheric Cosmogenic Radionuclides with Spacecraft Surfaces,* J.C. Gregory, G.J. Fishman, B.A. Harmon, T.A. Parnell, The LDEF First Post-retrieval Symposium, Orlando, FL; June 1991. NASA Conference Publication 3134, Part 1, p. 237-247. 92N 33294

3. *Effects on LDEF Exposed Copper Film and Bulk,* P.N. Peters, J.C. Gregory, L.C. Christl, G.N. Raikar, The LDEF First Post-retrieval Symposium, Orlando, FL; June 1991. NASA Conference Publication 3134, Part 2, p. 755-762. 92N 34816

4. *Measurements of Erosion Characteristics for Metal and Polymer Surfaces using Profilometry,* L.C. Christl, J.C. Gregory, P.N. Peters, The LDEF First Post-retrieval Symposium, Orlando, FL; June 1991. NASA Conference Publication 3134, Part 2, p. 723-735. 92N 34813

5. *Pinhole Cameras as Sensors for Atomic Oxygen in Orbit: Application to Attitude Determination of the LDEF,* J.C. Gregory, P.N. Peters, The LDEF First Post-retrieval Symposium, Orlando, FL; June 1991. NASA Conference Publication 3134, Part 1, p. 61-67.

6. *Interactions of Atomic Oxygen with Material Surfaces in Low Earth Orbit: Preliminary Results from Experiment A0114,* J.C. Gregory, L. Christl, G.N. Raikar, J.J. Weimer, R. Wiser, P.N. Peters, The LDEF First Post-retrieval Symposium, Orlando, FL; June 1991. NASA Conference Publication 3134, Part 2, p. 753. 92N 34815

7. *Optical Transmission and Reflection Measurements of Thin Metal Films Exposed on LDEF,* J.C. Gregory, Proceedings of the LDEF Materials Workshop '92, Langley Research Center, November 19-22, 1991. N15

MEASUREMENTS OF EROSION CHARACTERISTICS FOR METAL AND POLYMER SURFACES USING PROFILOMETRY

PREV. ANN
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SUMMARY

The surfaces of many materials exposed in low earth orbit are modified due to interaction with atomic oxygen. Chemical changes and surface roughening effects can occur which alter optical and other properties (ref.1). The experiment A0114 contained 128 solid surface samples, half of which were exposed on the front and half on the rear of LDEF. Each sample has been subjected to many analyses, but this paper will only describe the methods and techniques used to measure the changes in roughness, erosion depths and material growth using profilometry.

INTRODUCTION

The effect of atomic oxygen on materials is highly variable. No method of measuring the effects is optimum for all materials. We have developed several techniques found valuable in analyzing a wide range of materials, varying from minute effects on the level of atomic dimensions to heavily etched surfaces. One of the most effective techniques has been to utilize the measurement of etched steps at interfaces between exposed and unexposed, or masked, areas by stylus profilometry. Stylus profilometers typically measure the vertical displacement of a stylus (usually a fine pointed diamond) as it is scanned horizontally across the surface. Highly magnified vertical displacements are plotted against horizontal positions greatly exaggerating surface detail. This technique has the ability to measure a wide range of etch steps, from below 1 nm to 1 mm. For measurements below 1 nm it is essential that optically flat surfaces be used and that the steps be measurable over very short lateral distances. As shown elsewhere (ref.2), to produce etch steps over short lateral distances requires very thin masks, preferably thin film patterns resistant to atomic oxygen that are strongly bonded to the substrate being exposed, or at least knife-edged masks essentially in contact with the surface; these types of mask avoid structures which

* Work supported in part by grant from UAH Research Institute and NASA grant NAGW-812 and contract NAS8-36645.

shadow the sample from the incident oxygen, preventing etch profiles with wide lateral dimensions. Lack of shadowing is particularly important on surfaces experiencing little effect, since even optical flats have variations or waves on their surfaces which cannot be distinguished from etch steps unless the steps are very sharp or patterned. One of the best patterns is a series of closely spaced lines for the masks, which produce a square wave pattern in the surface, providing multiple steps for comparison. An alternative approach for some thin films is to scratch narrow grooves through the thin film but without damaging the substrate. The depth of the scratches in both exposed and unexposed regions is then measured at a number of locations. This works well for materials softer than glass but hard enough to avoid excessive formation of furrows adjacent to the scratches. When done properly, the scribe will not scratch the substrate and will leave a flat bottom in the scratched area, indicating the full thickness of the film has been removed, as opposed to a v-shaped scratch which offers no assurance of this. Not only can etch steps be measured this way, but contaminant layers or increases in thicknesses in exposed areas due to oxidation or other causes, can be determined accurately, sometimes to a few 0.1 nm. This latter ability is valuable in conjunction with optical measurements on thin films where it is not known whether an increase in light transmission is due to a thinning of pathlength by removal of material or a change in optical properties. Measurement of an increase in the film thickness in the exposed areas helps to establish the latter. Thus, some metals have volatile oxides and are thinned while some form stable, clear oxides and are thickened, but are more transmissive to light. Good reflectance measurements are also desired in conjunction with the transmission measurements to account for any contamination or surface changes.

MEASUREMENTS

A wide variety of material surfaces were exposed to the atomic oxygen fluence, UV degradation and space contamination in the LDEF-A0114 experiment. The atomic fluence for the LDEF was 9.73×10^{21} atom cm $^{-2}$ over its nearly six years exposure.

The surfaces consisted of polished bulk samples and high purity thin optical metal films sputtered or evaporated onto 1 inch flat fused silica disks. Each disk had one half of its surface masked, to be used as a control surface, and the other half was exposed to the environment. The samples were mounted in an aluminium panel, as shown in Figure 1. By masking half of each sample, it was possible to measure changes in roughness, erosion depths, material growth and changes in film thickness. These changes were measured, using a Taylor-Hobson Talystep Profilometer, model number 223-27, and a Taylor-Hobson Form Talysurf, model number 279-17.

The Talystep is a surface-profiling instrument designed to measure micro-thin film deposits, with a height resolution of ~1 Å and a lateral resolution of ~1μ. The one used for our measurements consisted of a conical diamond tip stylus of 1μm radius, with an adjustable force of 1 to 30 mgf. One mgf was used for tracing soft metals like Au, Ag and Sn films, to minimize damage to the surface. The Talystep measures the thickness of a film by moving the stylus at a constant rate across a groove cut in the film or across the step between the film and the substrate at the edge of the sample. To minimize thermal gradients and vibrations that affect the performance of the instrument on the most sensitive scales, the Talystep is enclosed in a plexiglas box and mounted on a vibration isolation table that in turn is placed on a granite slab in an air conditioned room (ref.3)

Calibration of the instrument was done using a standard provided by Taylor-Hobson. It is comprised of a frame and a base on which two glass plates are mounted. For checking the lower magnification ranges the left hand plate has three grooves nominally 2.5 micrometer deep with an uncertainty of ± 0.05 μm. To check the highest magnification; the right-hand plate has three grooves nominally 0.025 μm deep with an uncertainty of ± 0.005 μm.

The Talysurf instrument is similar to the Talystep but operates over larger ranges with lower resolution. The program supplied with this instrument is able to measure many different shapes. Also, the stylus loading force is much greater, with a range from 75 to 100 mgf. A statistical analysis package, provided with the system, calculates both the mean value and standard deviation of the data values obtained from a series of measurement. Corrections for the accurate movement of the stylus arm and the size and shape of stylus tip are made by the computer. In order for the computer to make these corrections, a series of constants, whose values represent the characteristics of the individual stylus geometry, are required. These constants can be input via the keyboard or determined from a calibration routine automatically.

DISCUSSION

Examples of applications of stylus profilometry to different materials illustrate its ability to measure numerous features of exposed and unexposed surfaces. Nine examples will be discussed here. Figure 2 illustrates the ability to measure the roughness of a typical coated surface (unexposed iridium) on an optical flat of moderate quality. The RMS roughness is strongly influenced here by the longer period wave on the surface compared to the short period roughness. A sharp transition is shown in Figure 3 for an iridium sample scanned from exposed to unexposed areas. Even though the surface has a wave associated with it, a step of ~3.6 nm increase in thickness on the exposed area is apparent. The roughness on the exposed surface is also obviously increased by spikes which so far have not been satisfactorily explained. The increase in thickness could result from contamination or modification of the film itself. Studies are still underway to interpret the cause. Figure 4 represents a stylus trace on the same iridium sample from unexposed to exposed area. Although the roughness of the exposed area varies over the surface, the increase in thickness is comparable (3.5 nm and 3.6 nm), except at the knife edge boundary for Figure 4; although the sloped surface of the knife edge might enhance contamination effects at the boundary, insufficient data exists to positively identify the cause of the feature.

The gold film also shows a similar increase in thickness on the exposed area (~3.5 nm) however the gold surface does not exhibit the spikes on the exposed surface that were observed on the iridium surface. Figure 5 shows a stylus trace across one scratch in the unexposed area. Figure 6 shows a stylus trace across two scratches in the exposed region. Note that the rms roughness includes the depth of the scratches. The actual rms roughness on exposed was ~1.0 nm and the unexposed was ~ 0.7 nm for the gold sample.

Figure 7 shows how multilayer coatings can be resolved by the scratching and profiling, in some cases. In this figure a silver film deposited over a carbon film was investigated. The two scratches gave ~19.4 nm and ~20.1 nm for the unexposed carbon thickness and ~33.3 and ~31.3 nm for the unexposed silver thickness. The exposed portion of the silver over carbon sample could not be resolved into two layers, but only one. The total thickness of this exposed area averaged ~112.2 nm compared to the total of ~52 nm for the unexposed area. See Figure 8.

Figure 9 illustrates etching of polycrystalline carbon of such magnitude that the etch depth exceeds the range of the Talystep used above and required the use of the Talysurf. The very rough nature of exposed combustible materials that erode heavily with formation of volatile products has been documented by SEM and other imaging techniques. The stylus profilometer provides accurate measurements of the spikes or plateaus that form at locations of slower etch, and provides an estimate of the maximum etch depth.

Polymethylmethacrylate, PMMA, is a plastic which is readily etched by atomic oxygen, forming a large number of small spikes at the bottom of the etch and a large etch step, as shown in Figure 10, and Figure 11. Figure 10, was traced on a sample mounted on the ambient temperature plate and Figure 11 is for a sample mounted on a separate thermally isolated plate of semipolished aluminum. The purpose was to examine the etch rate as a function of temperature. The small increase in etch in Figure 11 may be due to slightly higher temperature of the hot plate sample. The smooth plateau at the right of the etched area in Figure 10 is due to an artefact caused by the stylus catching on the large etch step and dragging the sample a short distance; heavily etched samples need to be secured for this reason.

CONCLUSION

Stylus profilometry is a very effective non destructive or minimal scratching technique to measure roughness, erosion depth and material growth of metals, polymers and carbons exposed to the atomic oxygen.

We have demostrated that these instruments (Talystep and Talysurf), used in combination with some of the techniques mentioned (scratching, step and transition measurements), have a wide range of resolutions, from ~1Å to a few hundred microns.

Examples, like iridium film, show the reliability of the instrument, giving the same thickness value for the transition in any direction scanned.

Stylus profilometry, by indicating decreases, or increases, in film thicknesses enables interpretations of changes in optical density measurements, i.e. whether thinning of the film or an increase in thickness with optical property changes are responsible for optical density changes.

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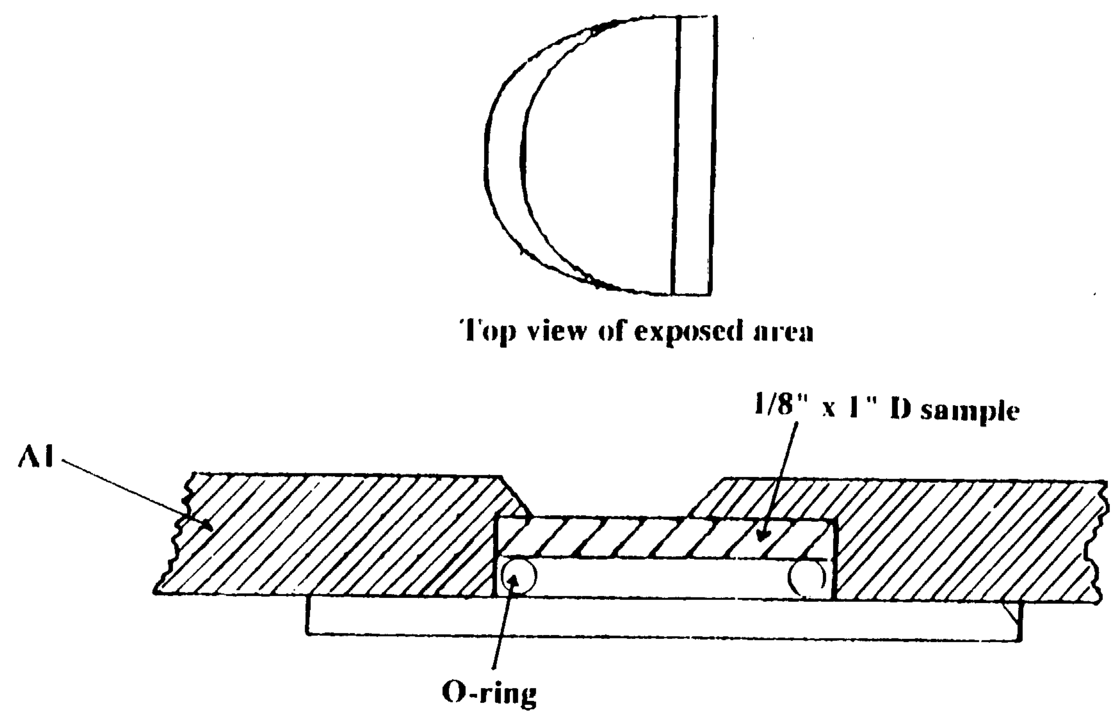

Figure 1. Cross-section of sample holder between exposed and unexposed areas

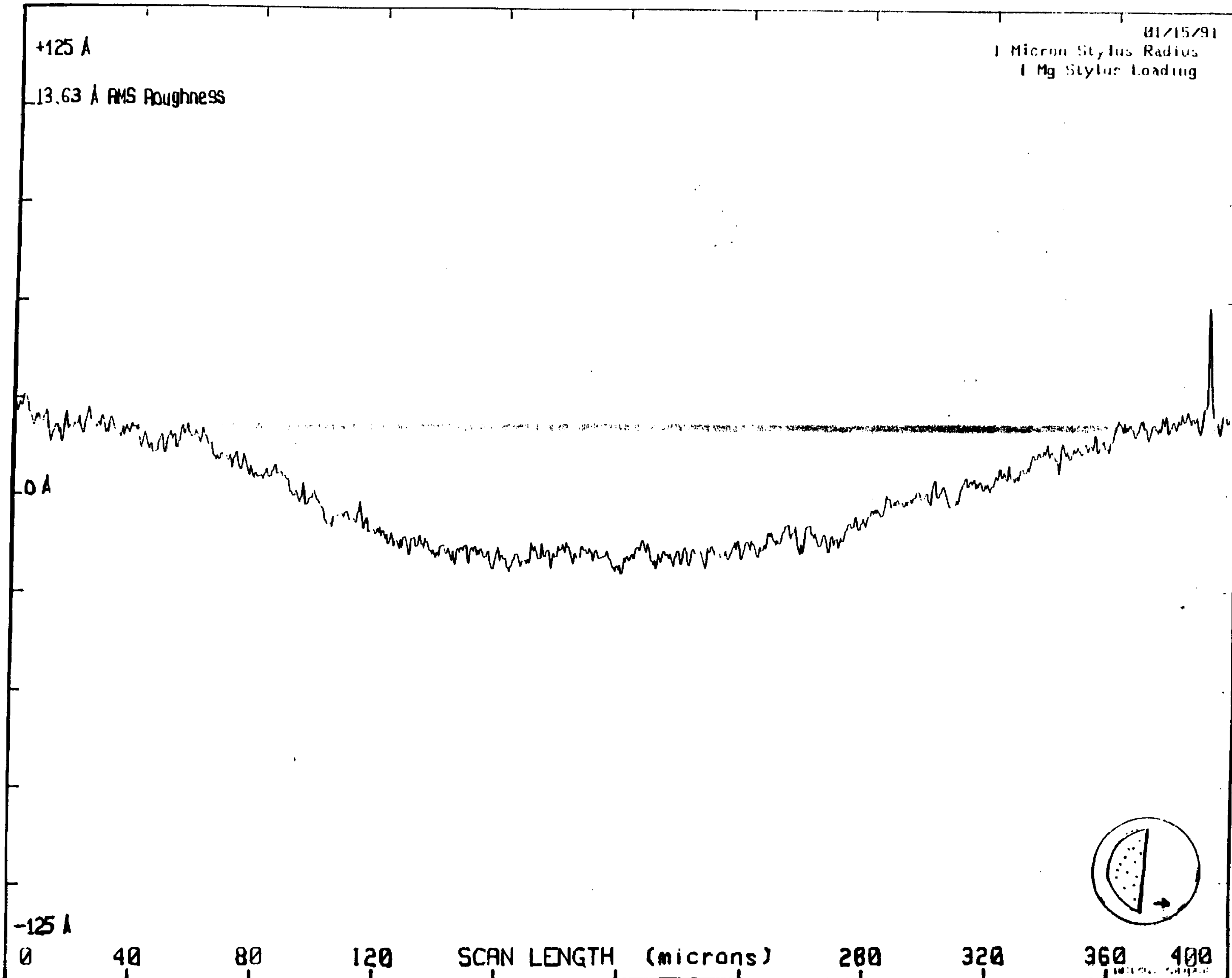

Figure 2. Surface profile of unexposed Iridium film

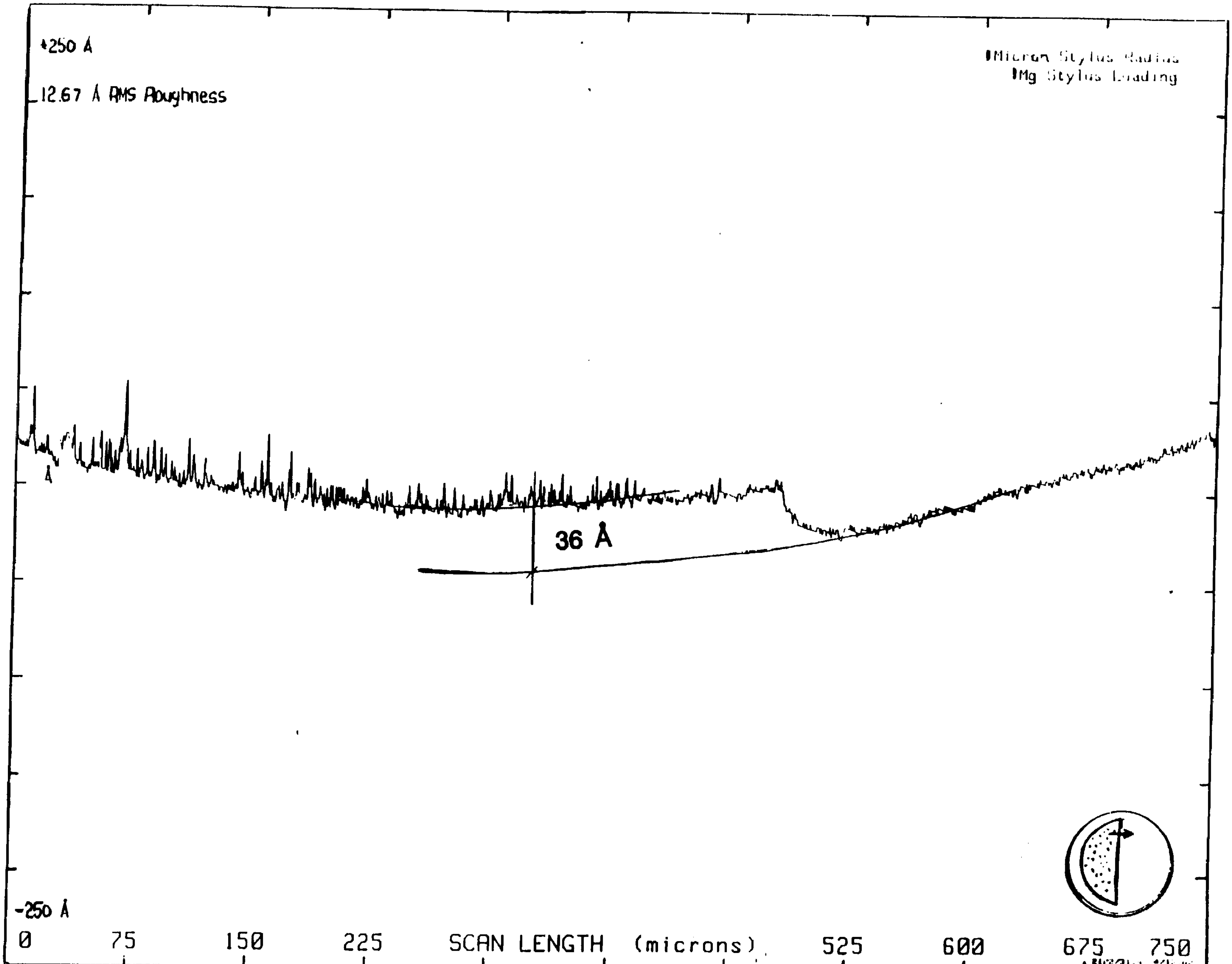

Figure 3. Surface profile of transition from exposed to unexposed of Iridium film

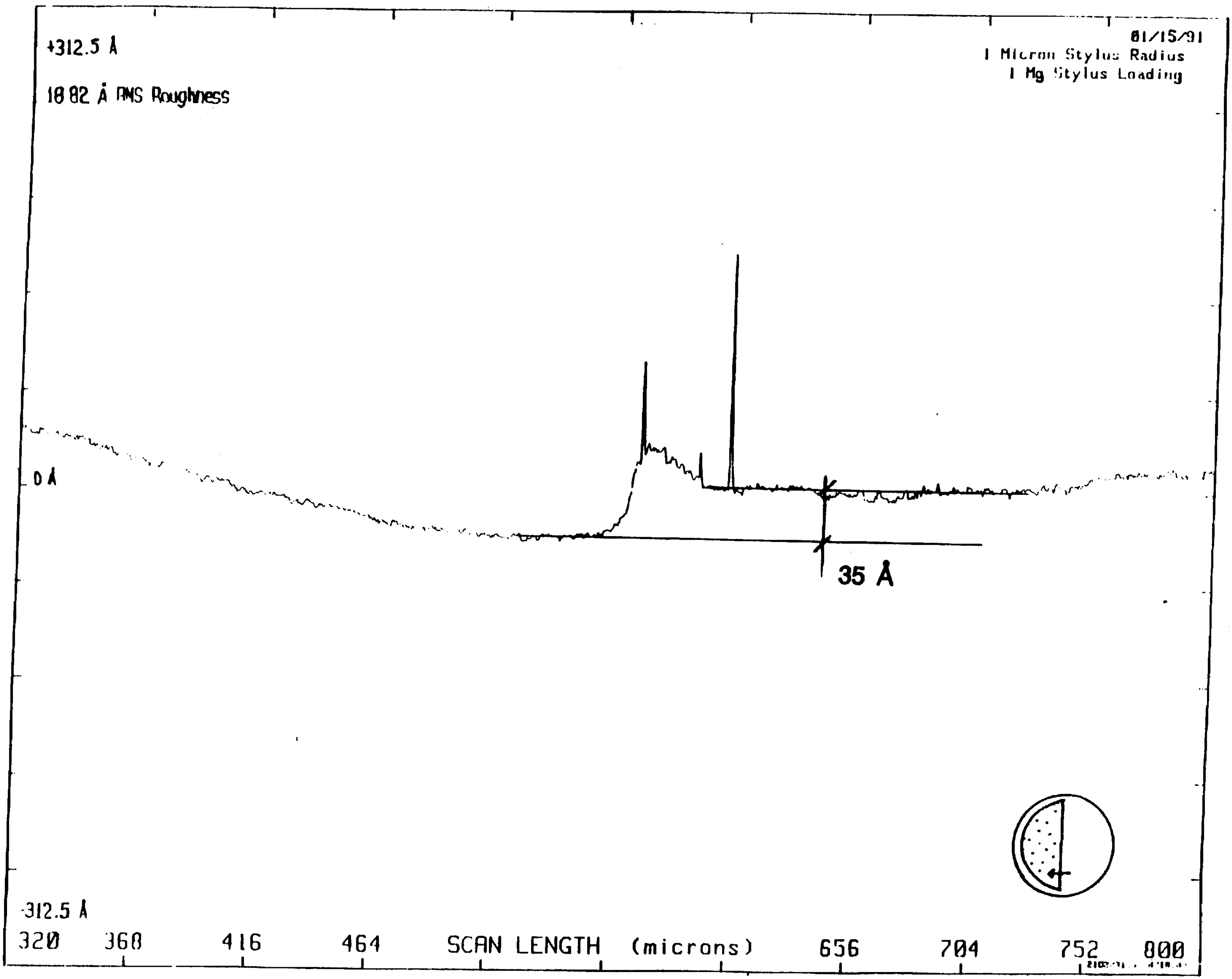

Figure 4. Surface profile of transition from unexposed to exposed of Iridium film

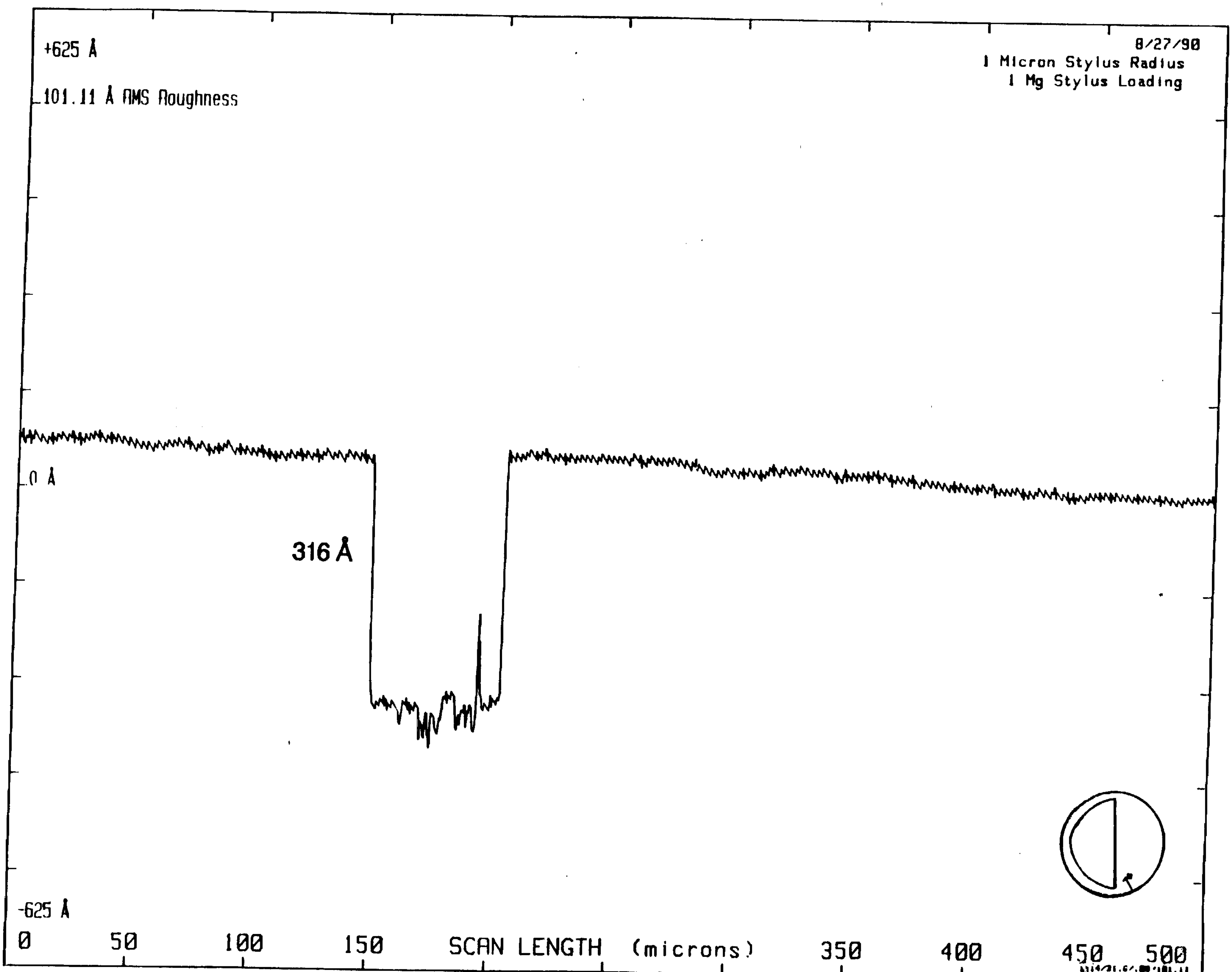

Figure 5. Surface profile of

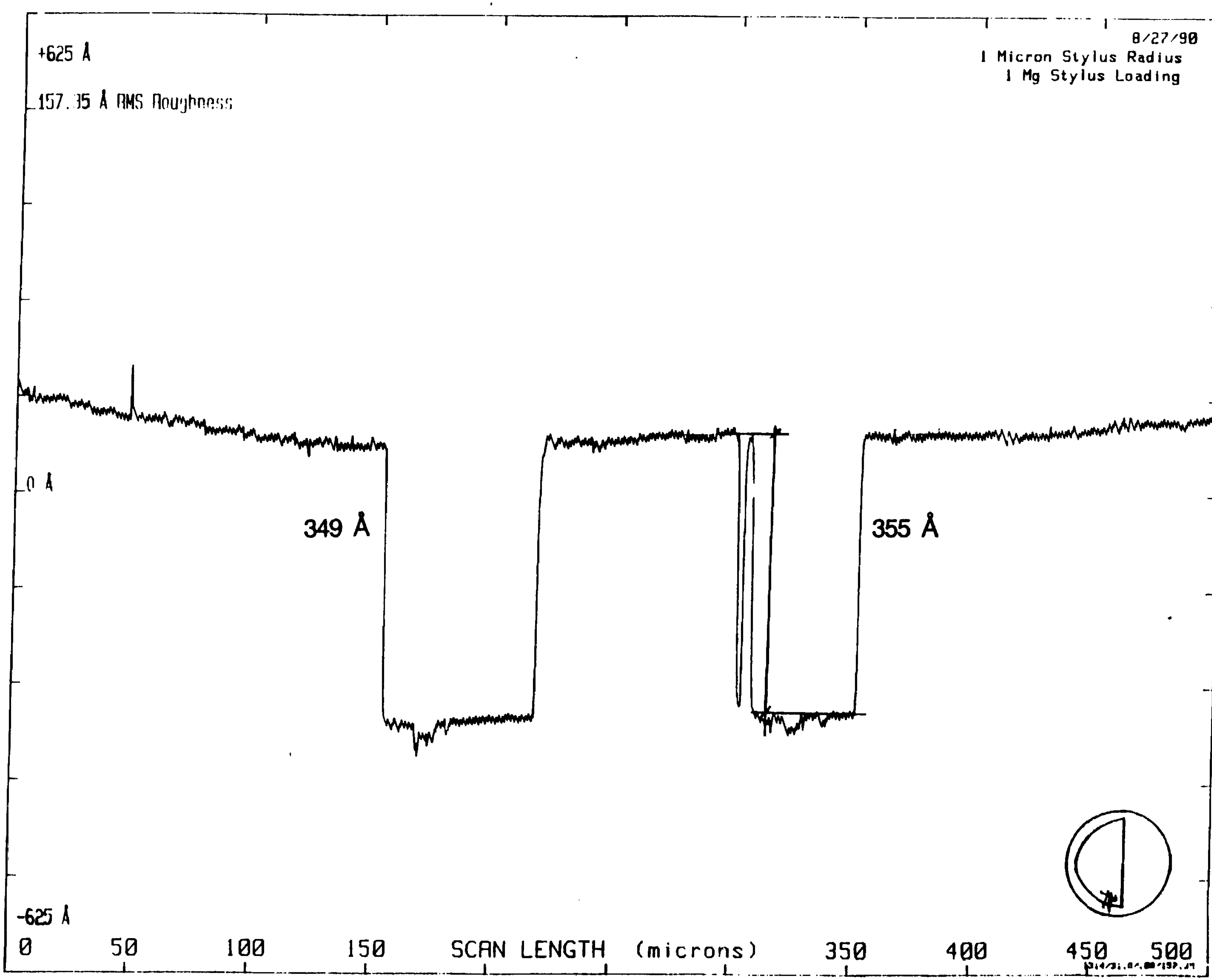

Figure 6. Surface profile of exposed Gold film

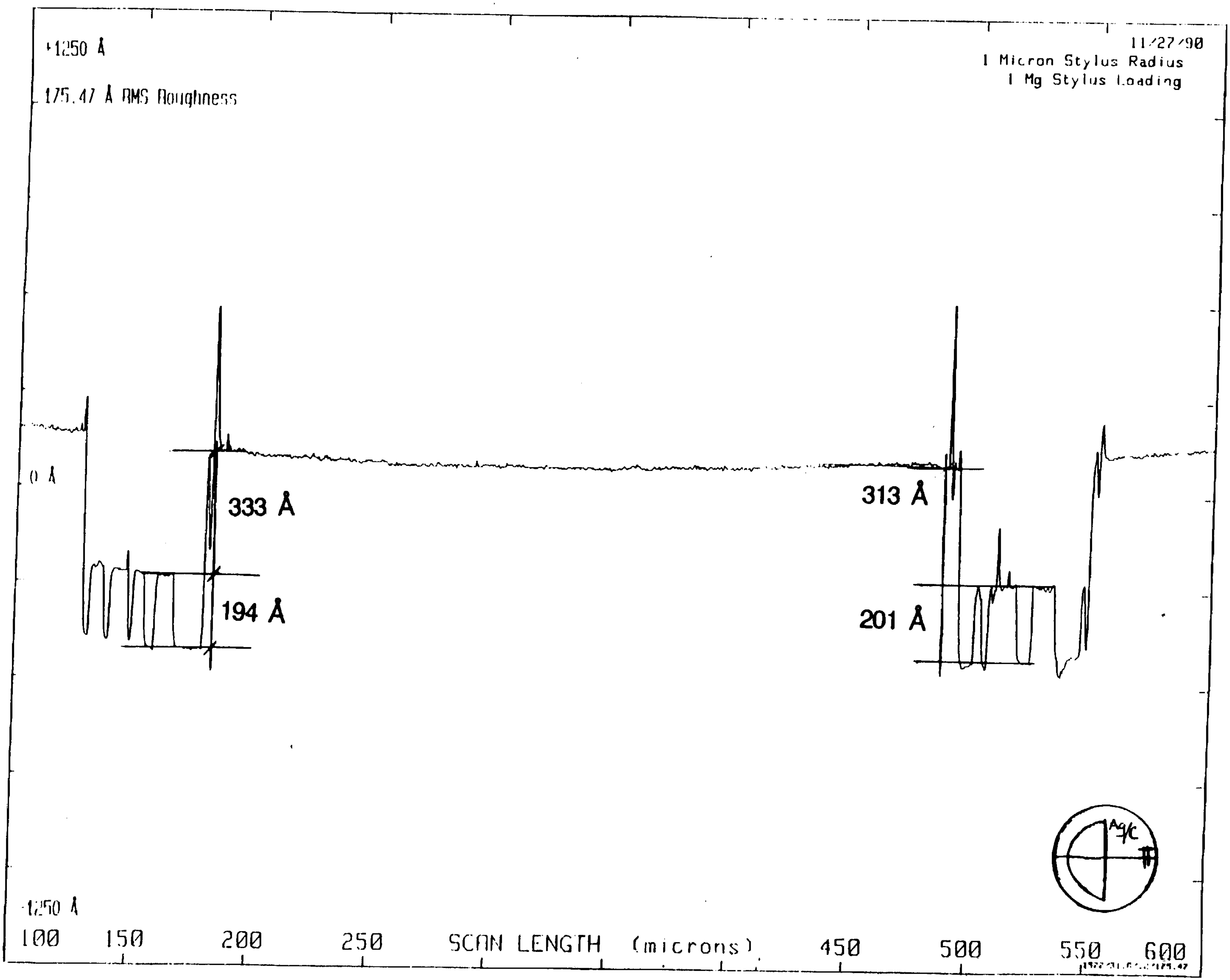

Figure 7. Surface profile of unexposed Silver over Carbon film

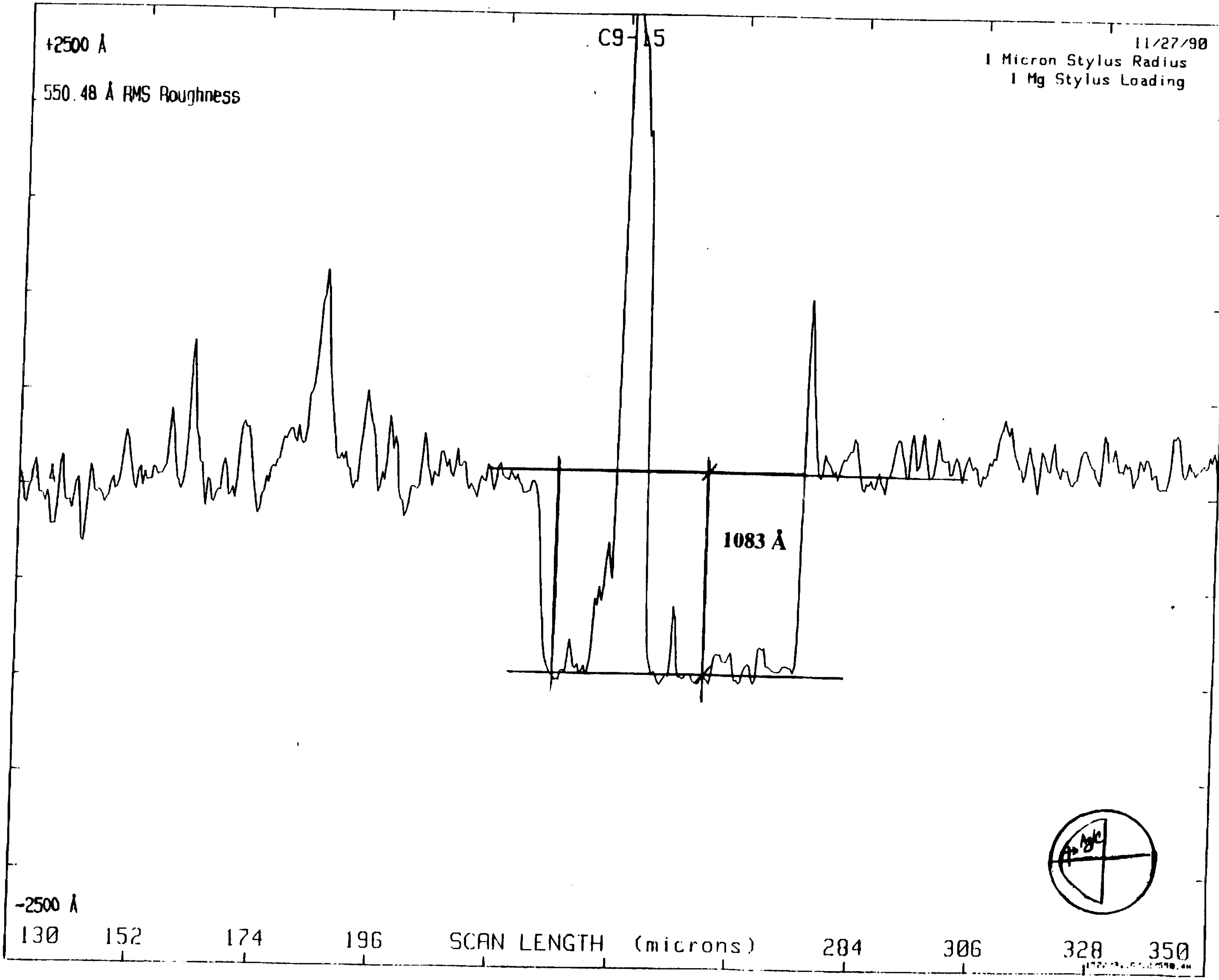

Figure 8. Surface profile of exposed Silver over Carbon film

Polycrystalline Carbon (C9-05)

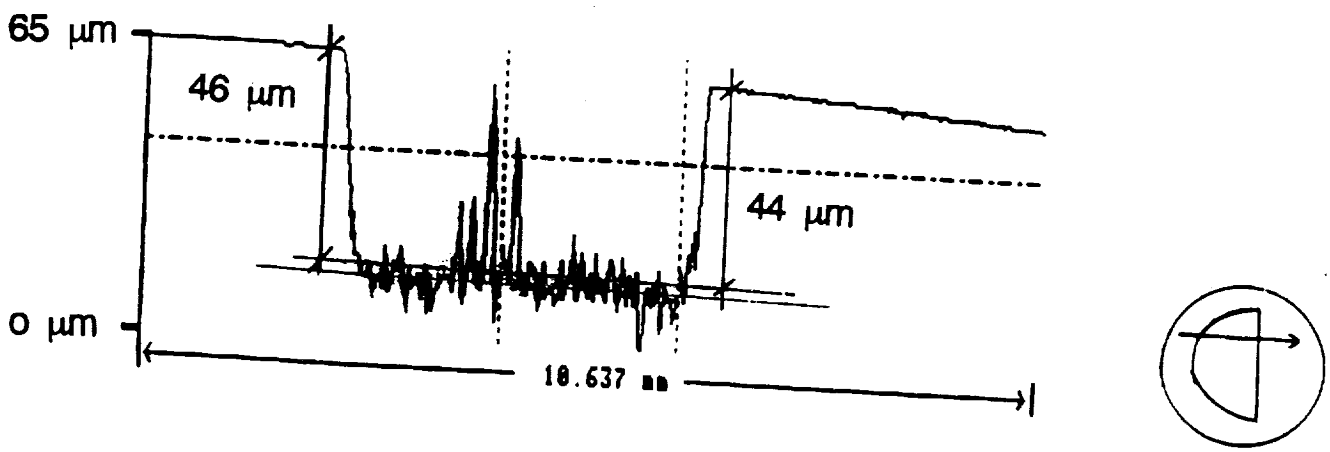

Figure 9. Surface profile of Polycristalline Carbon

PMMA (C9-31)

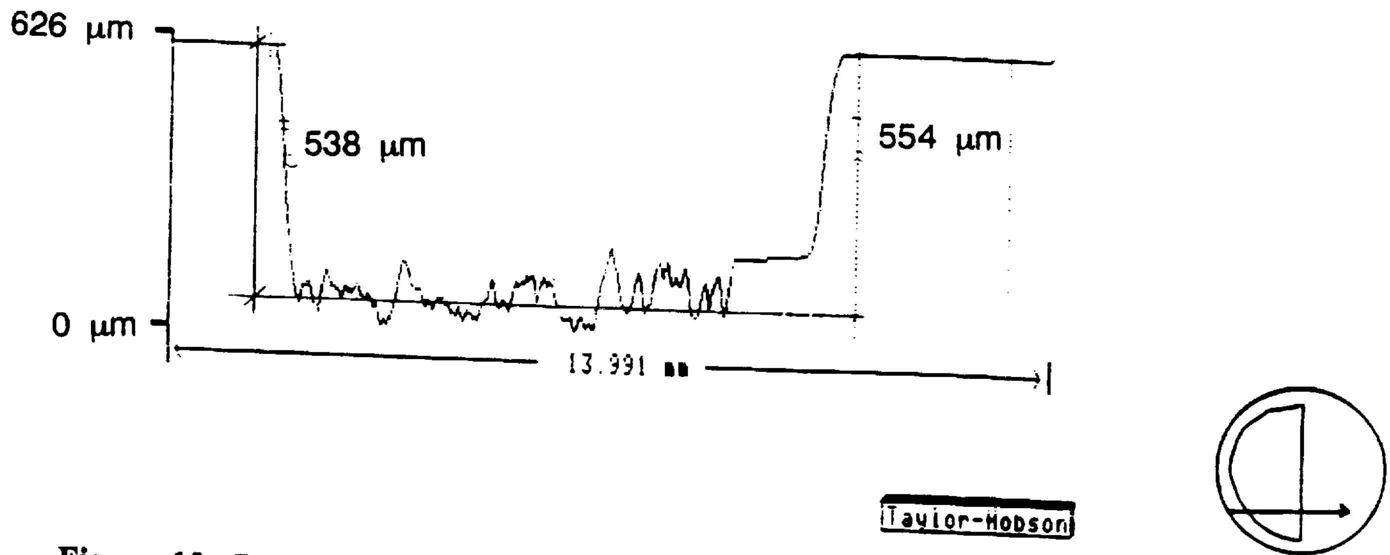

Figure 10. Surface profile of Polymethylmethacrylate at ambient temperature

PMMA (C9H-03)

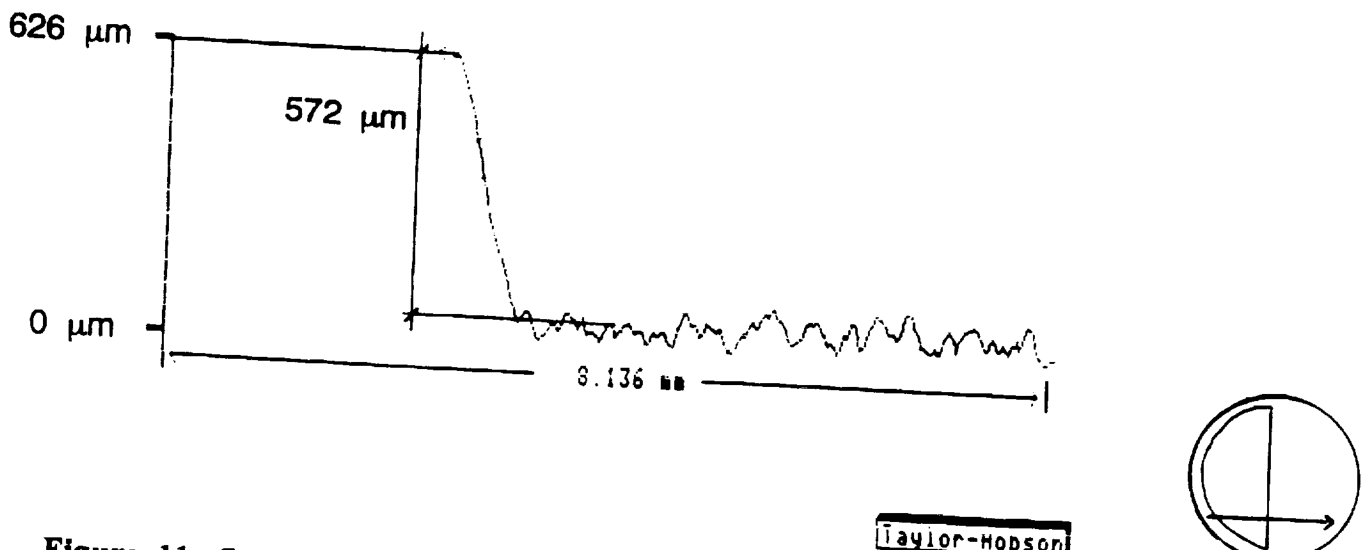

Figure 11. Surface profile of Polymethylmethacrylate at 10^0 C above the ambient temperature

PREV. ANN
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PINHOLE CAMERAS AS SENSORS FOR ATOMIC OXYGEN IN ORBIT; APPLICATION TO ATTITUDE DETERMINATION OF THE LDEF

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SUMMARY

Images produced by pinhole cameras using film sensitive to atomic oxygen provide information on the ratio of spacecraft orbital velocity to the most probable thermal speed of oxygen atoms, provided the spacecraft orientation is maintained stable relative to the orbital direction. Alternatively, as described here, information on the spacecraft attitude relative to the orbital velocity can be obtained, provided that corrections are properly made for thermal spreading and a co-rotating atmosphere. The LDEF orientation, uncorrected for a co-rotating atmosphere, was determined to be yawed 8.0° ± 0.4° from its nominal attitude, with an estimated ± 0.35° oscillation in yaw. The integrated effect of inclined orbit and co-rotating atmosphere produces an apparent oscillation in the observed yaw direction, suggesting that the LDEF attitude measurement will indicate even better stability when corrected for a co-rotating atmosphere. The measured thermal spreading is consistent with major exposure occurring during high solar activity, which occurred late during the LDEF mission.

INTRODUCTION

A requirement to study the LDEF attitude was identified and a pinhole camera was developed for this purpose as part of Experiment A0114 (refs. 1-3). The atomic oxygen sensitive pinhole camera uses the fact that oxygen atoms dominate the atmosphere in low-Earth orbits, and formation of a nearly

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collimated beam of oxygen atoms passing through a pinhole in a satellite front surface occurs as a result of the orbital velocity being greater than the most probable Maxwell-Boltzmann speed of the oxygen atoms. Thus, the range of incidence angles of atoms to satellite surfaces is very limited, as shown by the angular distribution curves for two different temperatures in fig. 1 and described in greater detail elsewhere (ref. 4). The same maximum oxygen atom intensity was used for both temperatures to illustrate how the intensity spreads into the wings for higher temperatures. A thin film of material (silver in this case), which is sensitive to atomic oxygen, then forms an image of the impact spot.

The temperature of the thermosphere depends upon solar activity; the 700 K temperature in fig. 1 is characteristic of a solar minimum and the 1500 K is closer to a solar maximum. LDEF altitude was high during the solar minimum of September 1986 (initially deployed at 480 km in April 1984) where oxygen density was lower and had decayed by the time solar maximum was reached in June 1989 (recovery occurred at 310 km in January 1990). Most of the exposure in the pinhole camera, occurred close to solar maximum when the altitude was lower, the oxygen density was greater, and the angular distribution for atom incidence was widest. As will be described later, a well-defined spot was measured on the pinhole camera's silver sensor surface. Although overall darkening from overexposure (scattered atoms within the camera) was observed, this spot has been interpreted as being from the direct incidence beam and was used to determine the orientation of the LDEF relative to the orbital velocity.

MEASUREMENTS

The pinhole camera consisted of a 0.3 mm thick stainless steel hemisphere 3.25 cm (1.28 in.) radius, polished on the concave surface and coated with vacuum-evaporated silver. Silver was used because it discolors from formation of oxide (ref. 5). The pinhole had a conical shape with an included angle much wider than the maximum atom incidence angle and terminated as knife edges at a pinhole diameter of 0.5 mm (0.020 in.). The pinhole was positioned at the center of the silvered hemisphere. As shown in fig. 2, the exposure at any point on the hemisphere will depend upon the solid angle subtended by the pinhole from that point and the point's angular displacement from the orbital direction, i.e., the atom fluence as a function of angle from the velocity vector as shown in fig. 1. For orientations within 10° of the orbital direction, the solid angle subtended by the pinhole is constant within 2%; the predominant effects of pinhole size and thus solid angle are to reduce the overall fluence, or exposure, and increase resolution by reducing pinhole size.

Thus, the spot produced behind the pinhole should be centered with the LDEF's velocity vector and the spot's intensity should correspond to the distribution shown in fig. 1. Any variation in the attitude of the LDEF's velocity vector relative to the atmosphere would cause the spot to wander, producing a nonspherical, larger than normal, spot compared to that produced by thermal spreading of the beam.

Two techniques were used to determine the spot center and its shape: the first technique involved measurements taken directly from an enlarged photograph of the hemisphere taken on-axis with a 120 mm format camera and a 80 mm macro lens, and the second technique involved digitizing a 512 x 512 pixel CCD video camera image of the hemisphere and processing it to obtain both the spot and hemisphere centers and the spot geometry. Both techniques gave similar results.

DISCUSSION

Assuming that misalignment of the pinhole camera relative to the LDEF frame was negligible (machined surfaces and robust structures offer assurance of this), an LDEF orbiting with nominal attitude should have produced a spot centered on the hemisphere and uniformly round. The actual spot, as shown in fig. 3, was off-center, as would be produced by $8° \pm 0.4°$ clockwise yaw viewed from the space end. The spot was elliptical (major axis 14.8° and minor axis 14.1°, as subtended from the pinhole), with the major axis in the satellite yaw direction. It is noted that a yaw of 8° should have narrowed the spot in the yaw direction, not widened it as observed; thus, an oscillation in atom incidence along the yaw direction is the likely cause. This originally led us to conclude that the LDEF oscillated in the yaw direction (i.e., about its long axis), but it has been brought to our attention (Bourrassa, private communication, 1990) that a co-rotating Earth's atmosphere interacting with an inclined orbit produces an oscillation in the angle of incidence of oxygen atoms at the surface. We have verified that the oscillation occurs in the yaw direction, as observed, but the maximum range should be about $\pm 1.5°$, not the estimated $\pm 0.35°$ obtained from the ellipticity measured on the spot. While the center of the spot is rather well defined and is believed to be the average orientation for the LDEF, oscillations, thermal spreading, and other influences on exposure, such as multiple scattering must be separated. Some considerations are:

1. The exposure of the silver was an integrated effect which occurred over 5 3/4 years, over a wide range in oxygen atom temperature, and with an excess background from multiply-scattered atoms. However, most of the oxygen exposure was received during the last six months of the flight.

2. We have not been able to depth profile the exposed silver film, particularly across the spot. Although a nearly circular bulleye pattern suggests a profile similar to those in fig. 1, we have not yet devised a satisfactory technique for measuring optically opaque profiles.

3. Without a depth-composition profile it is not possible to fit the oxygen exposure to a known temperature distribution and there is some uncertainty as to the exact limits of the spot diameter (i.e., where the spot ends and the background takes over); however, it appears that rings on the spot represent equal thicknesses of oxide and provide the measured ellipticity. The minor axis of the spot could represent temperatures as high as 1500 K if assigned FWHM in fig. 1.

4. An oscillating structure and the apparent oscillation caused by an inclined orbit and rotating atmosphere do not yield the same angular flux distribution in a pinhole camera. An oscillating structure sweeps rapidly through the zero displacement and pauses at the extreme angular displacement; The opposite is true for the rotating atmosphere effect. Thus, a mechanical oscillation has a larger integral effect on spot diameter for the same number of degrees of oscillation. We are calculating these profiles with atmospheric oscillations included. Further study is needed to accurately determine the LDEF's range of oscillation.

Analysis by x-ray diffraction of the black powder flaking from much of the camera interior confirmed that it was Ag_2O. For reasons yet unknown, the primary exposed spot was more stable than the rest of the background exposed surface; this assisted our investigation.

AKNOWLEDGEMENTS

The authors are grateful for continued assistance from David Carter, William Kinard, and Jim Jones of the NASA Langley Research Center; to Howard Foulke of the General Electric Company for explanations of their satellite stabilization studies; to William Witherow for digital image measurements; and to Charles Sisk for computer assistance.

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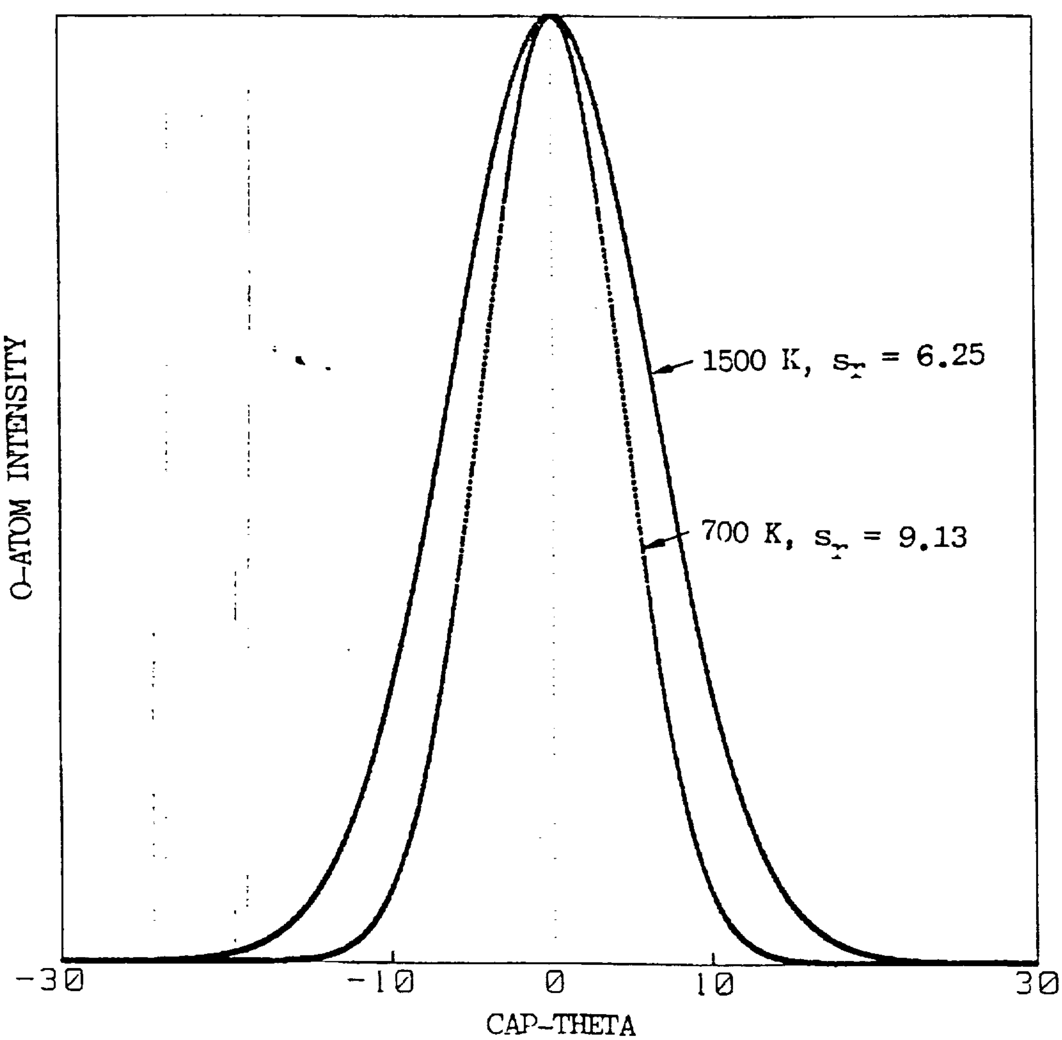
FIGURE CAPTIONS

Fig. 1. Intensity of oxygen atoms versus incidence angle, cap-theta, in degrees from the orbital ram direction for two equilibrium temperatures of the atoms.

Fig. 2. Schematic of pinhole camera with off-centered spot due to yaw of the LDEF and showing thermal spreading about the spot center due to the effect shown in Fig. 1.

Fig. 3. Photograph of exposed silver hemisphere from pinhole camera; overall dark flaking area is interpreted as overexposure from multi-scattered atoms, and the spot, which is more stable, is believed to be from direct incidence.



O-ATOM INTENSITY
1500 K, s_r = 6.25
700 K, s_r = 9.13
-30
-10
0
10
30
CAP-THETA

Fig. 1

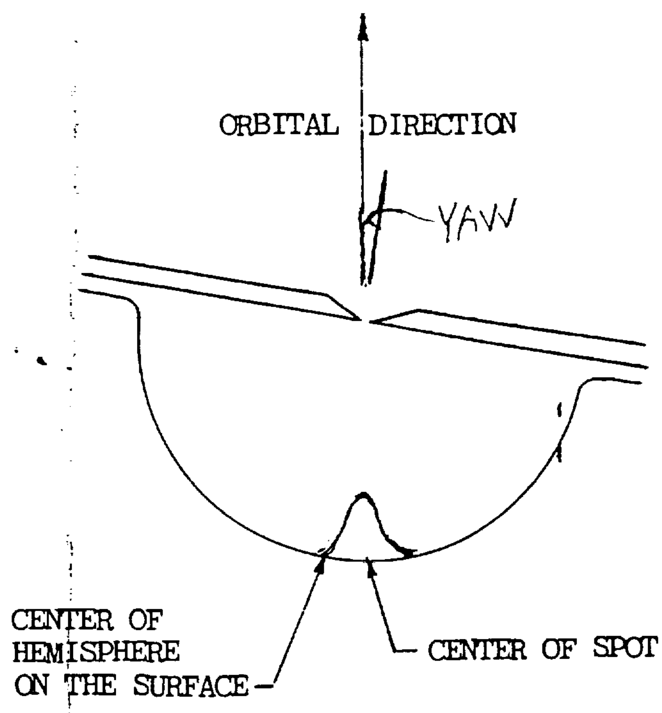

ORBITAL DIRECTION
YAW
CENTER OF
HEMISPHERE
ON THE SURFACE
CENTER OF SPOT

Fig. 2

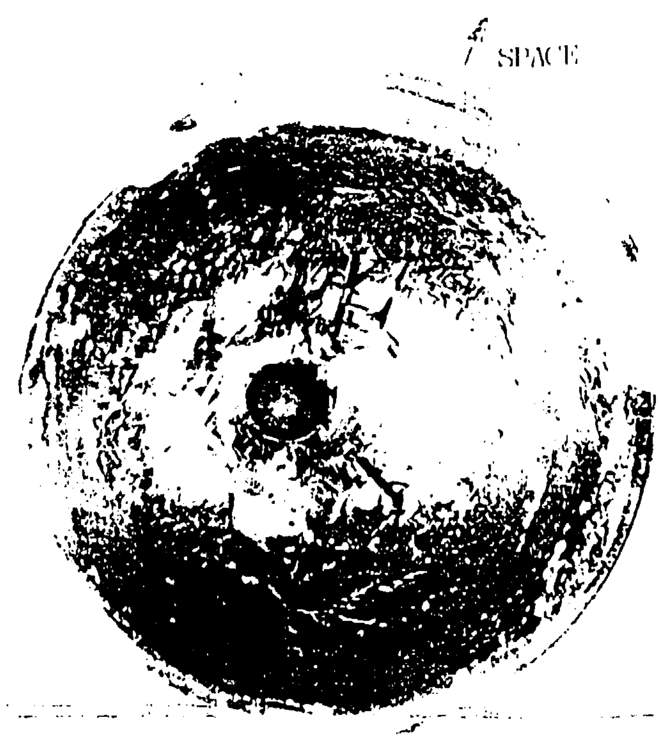


Fig. 3

INTERACTIONS OF ATOMIC OXYGEN WITH MATERIAL SURFACES IN LOW EARTH ORBIT: PRELIMINARY RESULTS FROM EXPERIMENT A0114

PREV ANN
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ABSTRACT

The UAH atomic oxygen experiment consisted of two trays (one-sixth of an LDEF tray each) of 64 one inch diameter solid samples. One tray was placed on the leading edge C9 and one on the trailing edge C3 of the spacecraft. Half of each sample was covered to provide a control. Thus it was intended that the effects of atomic oxygen and solar UV irradiation on the surface properties of each material could be distinguished from each other and from the effects of aging. Sixteen of the samples were placed on a thermally isolated plate of highly polished aluminum, while the main plate was coated with the thermal control coating S13-GLO. Though the experiment was entirely passive it was hoped that effects of thermal activation might be observed, if present. The plates were expected to stabilize at temperatures differing by 20 - 30°C. The experiment also carried a device to measure the spacecraft altitude (reported elsewhere at this meeting) and several oxygen atom reflectometers which have not been analyzed to date.

The samples included thin films of metals Os, Ir, Pt, Ni, W, Mo, Al, coated onto fused silica optical flats, metal carbides (WC, SiC), solid carbons of various types, eight polymers and some other coatings of various types.

Analysis is essentially complete using stylus profilometry with the high sensitivity Talystep and the lower sensitivity Talysurf machines. Though the integrated fluence of O atoms on LDEF was 30 times that on previous missions, etch depths on polymers such as the polyimide Kapton show excellent agreement with extrapolations from previous flight data . Some new effects are however observed. We have shown in a previous experiment on STS-8 that profilometry of this kind can show steps of 50 Å (for example those due to oxide film growth on metals) and this is now the preferred method for estimating etch depth (or mass loss) of erodible substances. We have also begun surface analysis of the materials using FTIR, SEM, XPS and Auger electron spectroscopies.

Experiment No. A0114

LDEF Workshop, Langley Research Center
November 19-22, 1991

EROSION RATES FOR POLYMERS MEASURED ON LDEF

S1-27

N93-11994

p. 22

John Gregory
The University of Alabama in Huntsville

Experiment A0114

- Polymers measured:

  Aromatic polyimide (Kapton - H film)
  Polyamide (Nylon)
  Polytetrafluoroethylene (PTFE)
  Polyethylene
  Polystyrene
  Polyvinyltoluene (PVT)
  Polymethylmethacrylate (PMMA, Lucite)

EROSION DEPTHS AND RATES FOR POLYMERS MEASURED ON LDEF

EXPERIMENT A0114 (UAH)

All data from samples on Row 9 (leading edge –8 deg.)

Polymer	Erosion Depth + (μm)	Reaction Rate * (cm^3 $atom^{-1}$)
Kapton	260 ± 5	2.89 ± 0.06
Nylon	253 ± 19	2.8 ± 0.2
Polystyrene	375 ± 15	4.17 ± 0.17
PVT	396 ± 27	4.4 ± 0.3
PMMA	566 ± 28	6.3 ± 0.3
Polyethylene	357 ± 21	3.97 ± 0.23
PTFE	33.5 ± 5	0.37 ± 0.06

* **Assuming an LDEF fluence for row 9 of 9.0×10^{21} atoms cm^{-2}**

\+ **Errors quoted in parenthesis (except for Kapton) are simply the RMS roughness of the exposed area. This is usually much rougher than the unexposed.**

COMPARISON OF EROSION YIELDS FROM LDEF EXPERIMENT A0114 WITH PREVIOUS DATA FROM STS-8 AND STS-41G

Material	Erosion Yields†; cm^3 (oxygen atom)$^{-1}$ LDEF Value (this work)	Prior Value
Kapton	2.89 ± .06	3.00**
PTFE (or FEP)	0.37 ± .06	0.1 – 0.5
polyethylene	3.97 ± .23	3.32 – 3.74
PMMA	6.3 ± 0.3	4.91*
PMMA		3.14
polystyrene	4.17 ± .17	1.7
Carbon; (HOPG)	1.04	0.6*
Carbon; pyrolytic polycrystalline	0.61	0.58

* Indicates UAH measurement on STS-8. Other values are from tabulations of others' data by JSC and LeRC.

** Error not quoted, may be 10-20%.

† Erosion yields for LDEF are based on a preliminary fluence of 9.0×10^{21} atoms cm^{-2}.

Summary

In general, agreement is reasonably good between erosion rates from the UAH LDEF experiment and prior data obtained at much lower mission fluences. Agreement is particularly satisfying in the case of Kapton where the prior database is large.

We note that, in spite of the known presence of silicaceous contamination on LDEF surfaces, the erosion rates of the highly erodible materials are hardly affected, if at all.

Caution is needed in comparing profilometry data (all UAH data is of this type) with weight-loss data. In profilometry we establish a ground-level of unimpeded erosion and ignore pinnacles and mesas where the material may have been protected by some foreign material.

We do not understand the difference between our own values of erosion for HOPG graphite on STS-8 and LDEF.

CHANGES IN OPTICAL PROPERTIES OF METAL FILMS EXPOSED ON LDEF

University of Alabama Experiment A0114

John Gregory
UAH

Palmer Peters
NASA, MSFC

- **Metals:**

Nickel	**~400Å**		
Gold	**350Å**		
Niobium	**300Å**	**+**	**100Å**
Iridium	**300Å**		

- **All sputtered films on optical quality fused silica substrates**
- **No interface binder coating used**
- **All films partially transmitting at visible wavelengths**

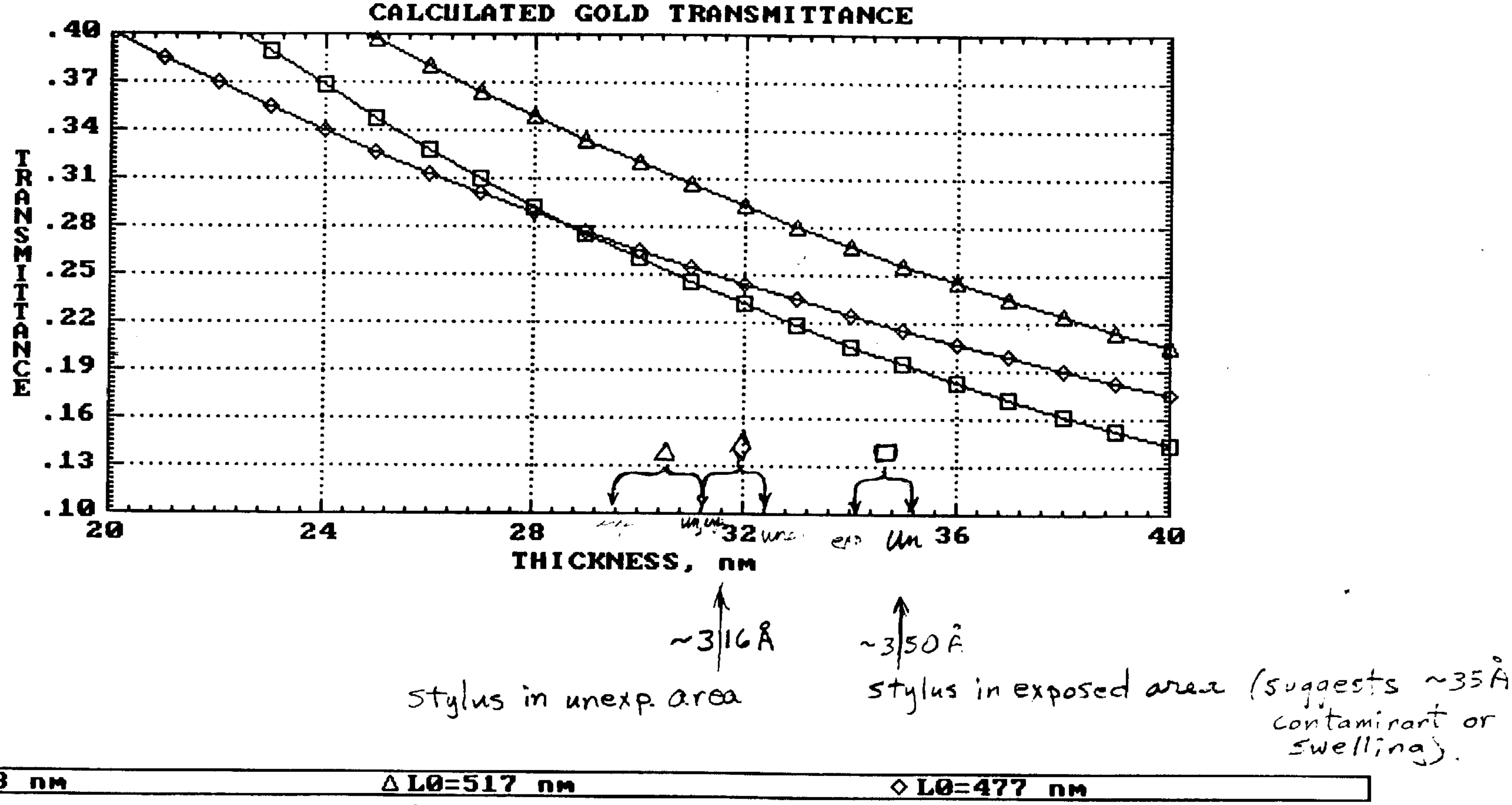
Measurements included in this discussion:

- Reflectance over the wavelength region 250 - 2500 nm
- Transmittance at 4 wavelengths in the visible
- Stylus profilometry (Ir)
- Optical microscopy (Ir)

LDEF Exposure (6 yrs) Materials List A0114

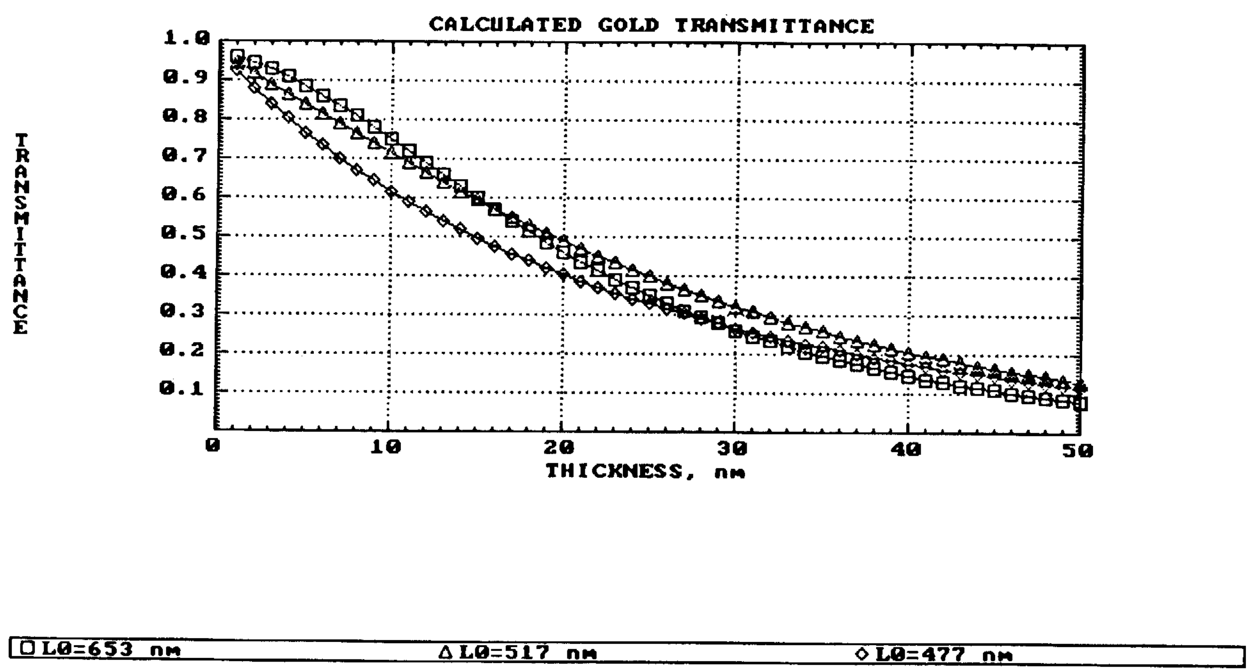
Metal Films	Non-metals (solid flats)	Polymers
Ag	C	Lucite
Au	Si	PVT
Au on C	Ge	Kapton
Sn	C (single crystal)	Mylar
W		Teflon
Pt		Nylon
Os		Polystyrene
Ir		
Au on Ag	SiC	
Ge	MgF_2	
Cu	BaF_2	
Ta	CaF_2	
Nb	LiF	
Mo	WC	
Mg		
Au on Nb		
Ni		

CALCULATED GOLD TRANSMITTANCE



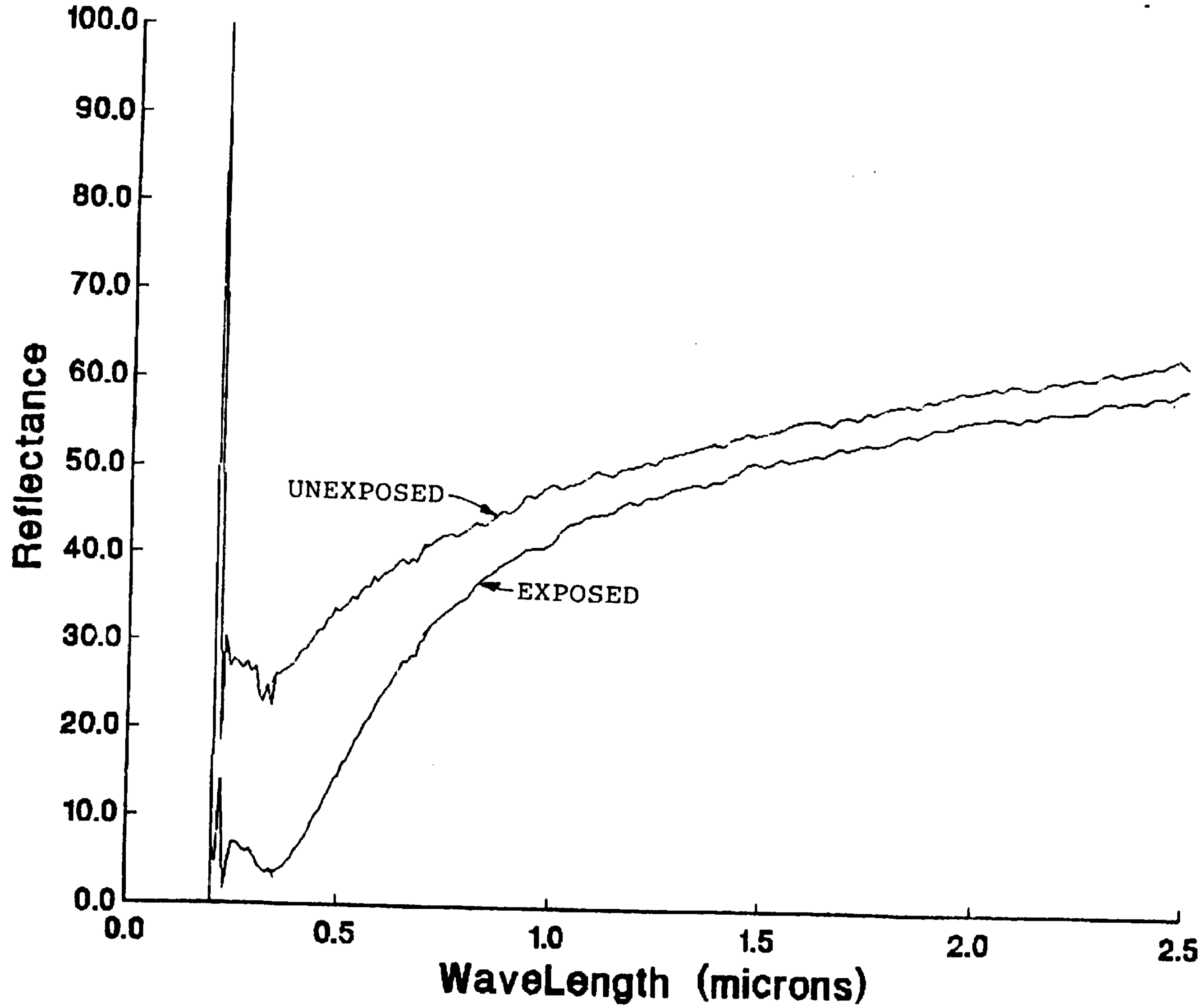
Measured change in T in:	equivalent thickness change unexp.	
Red	-10 Å	
green	-17 Å	aver. -13 Å
blue	-12 Å	

ORIGINAL PAGE IS
OF POOR QUALITY

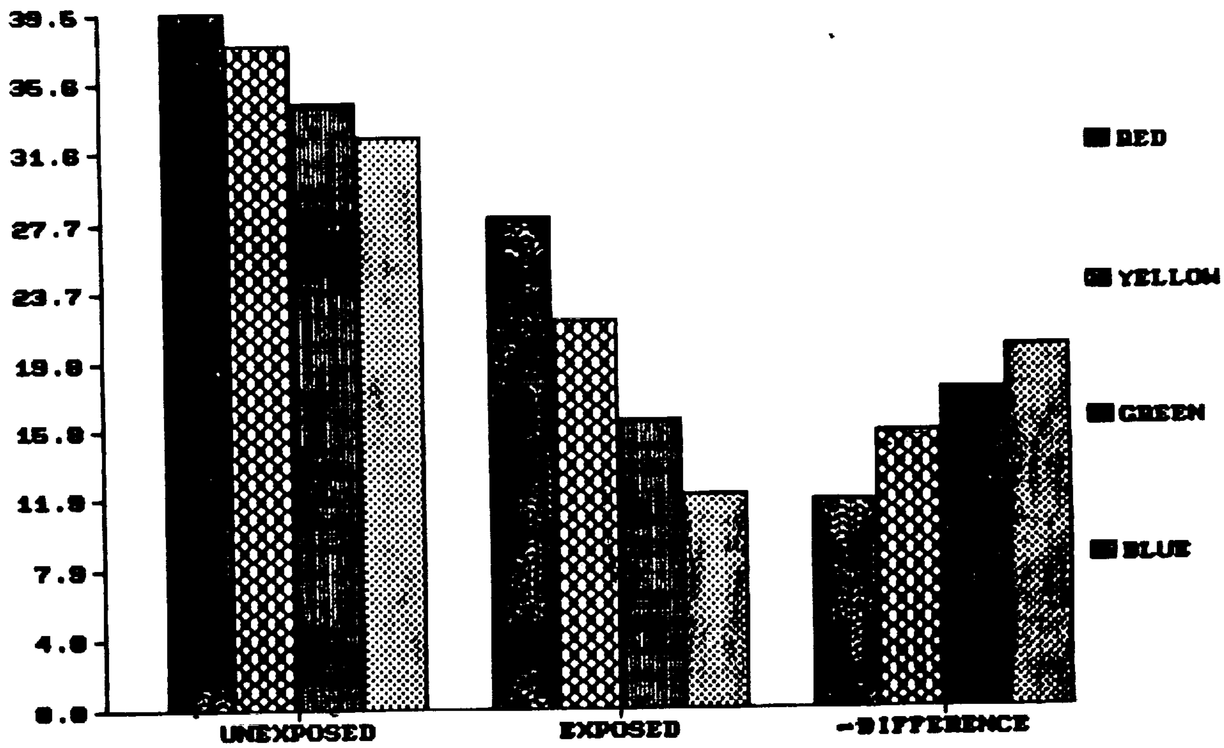

CALCULATED GOLD TRANSMITTANCE
TRANSMITTANCE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
THICKNESS, nm
□ L0=653 nm
△ L0=517 nm
◇ L0=477 nm

A0114 ①

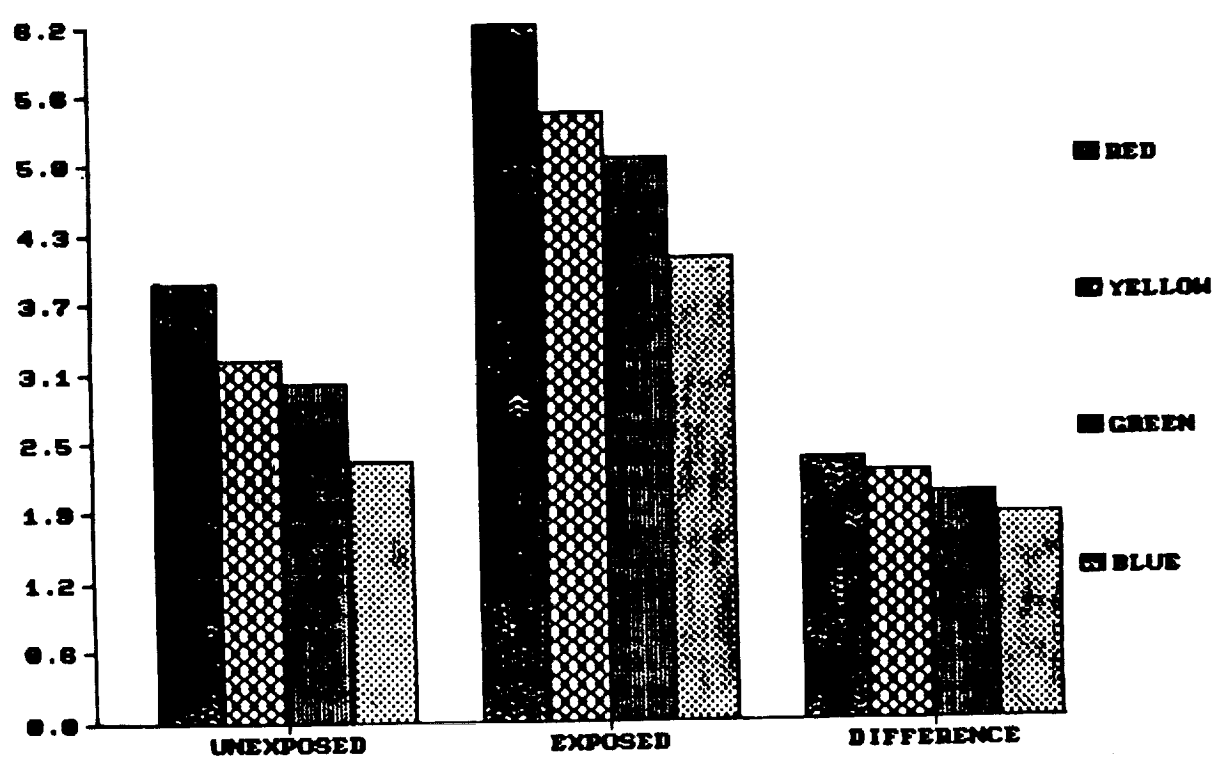
LDEF, A0114, C9-45, Ni FILM, % REFLECTANCE



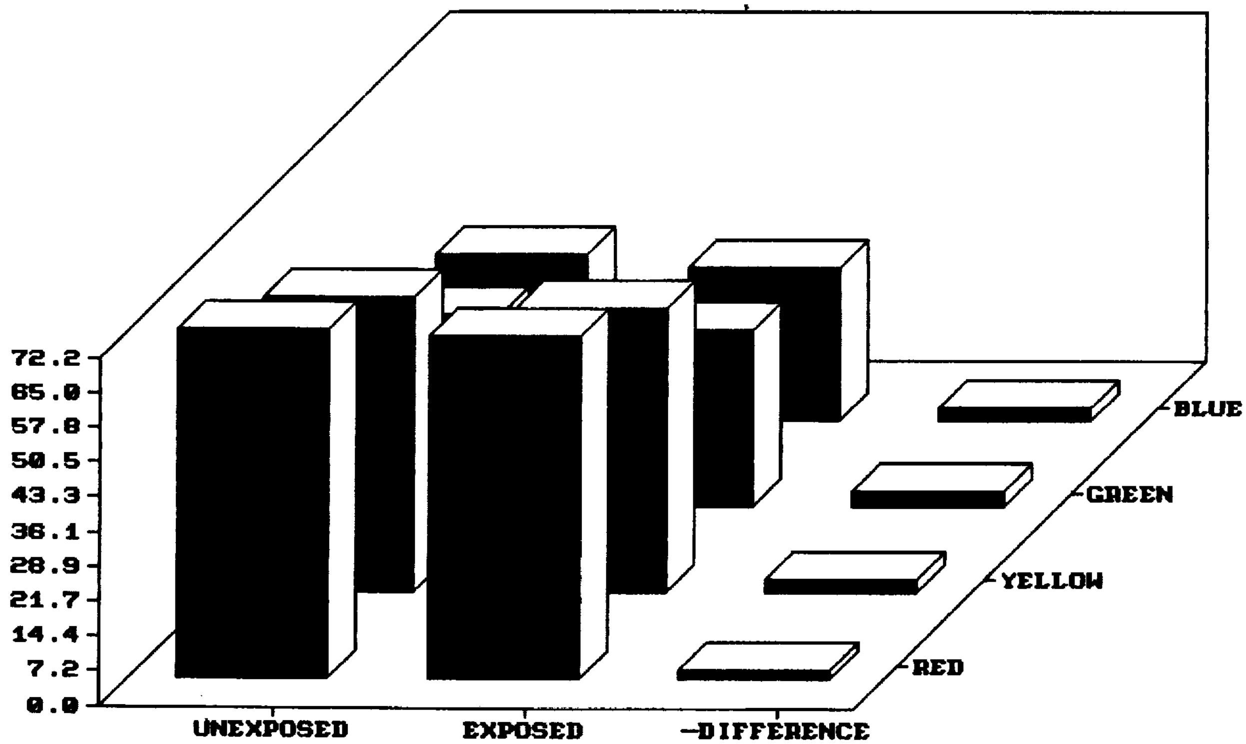
LDEF, A0114, C9-45, Ni FILM, REFLECTANCE (PERCENT)



LDEF, A0114, C9-45, Ni FILM, TRANSMITTANCE (PERCENT)

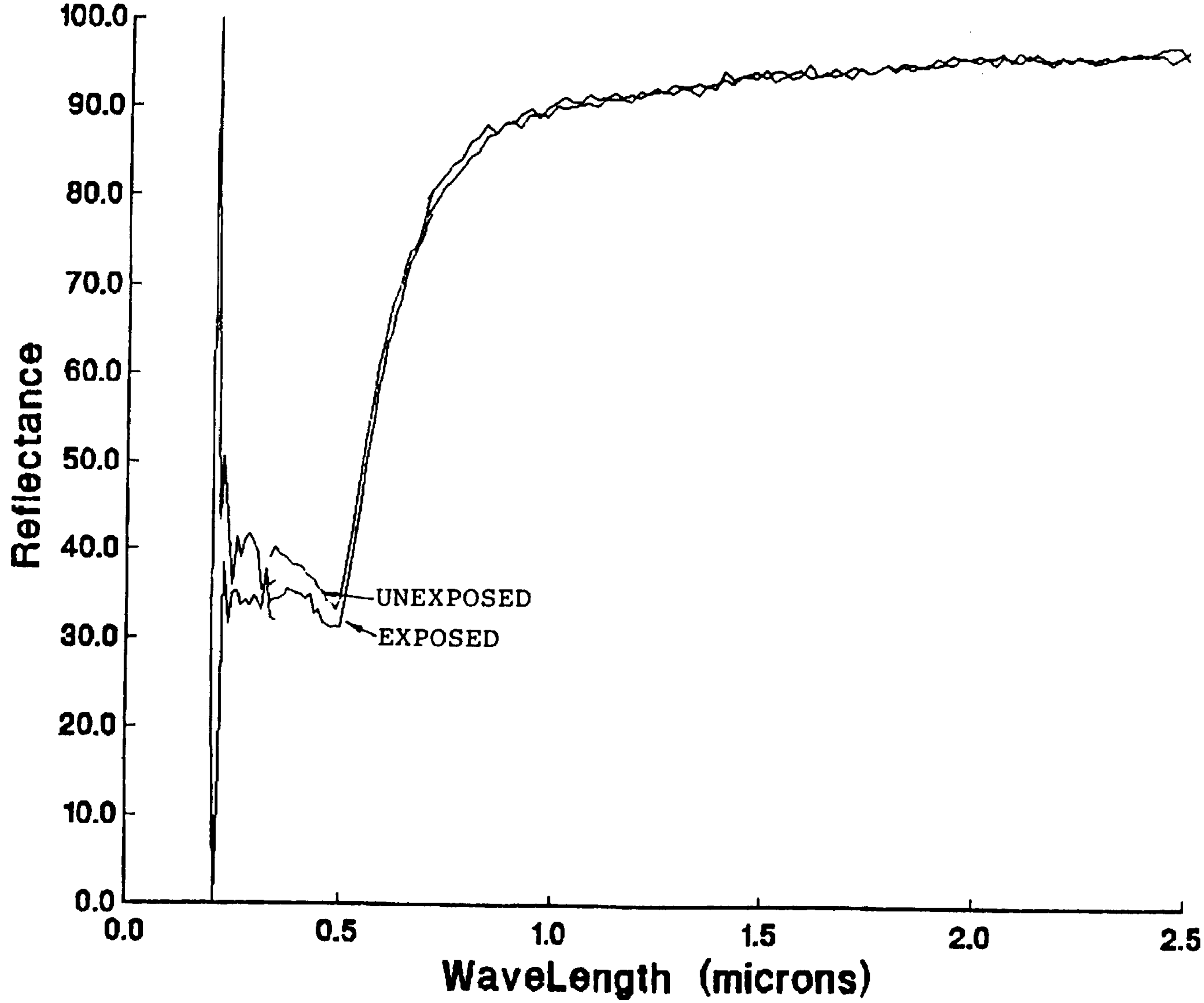


LDEF, A0114, C9-46, Au FILM, REFLECTANCE (PERCENT)

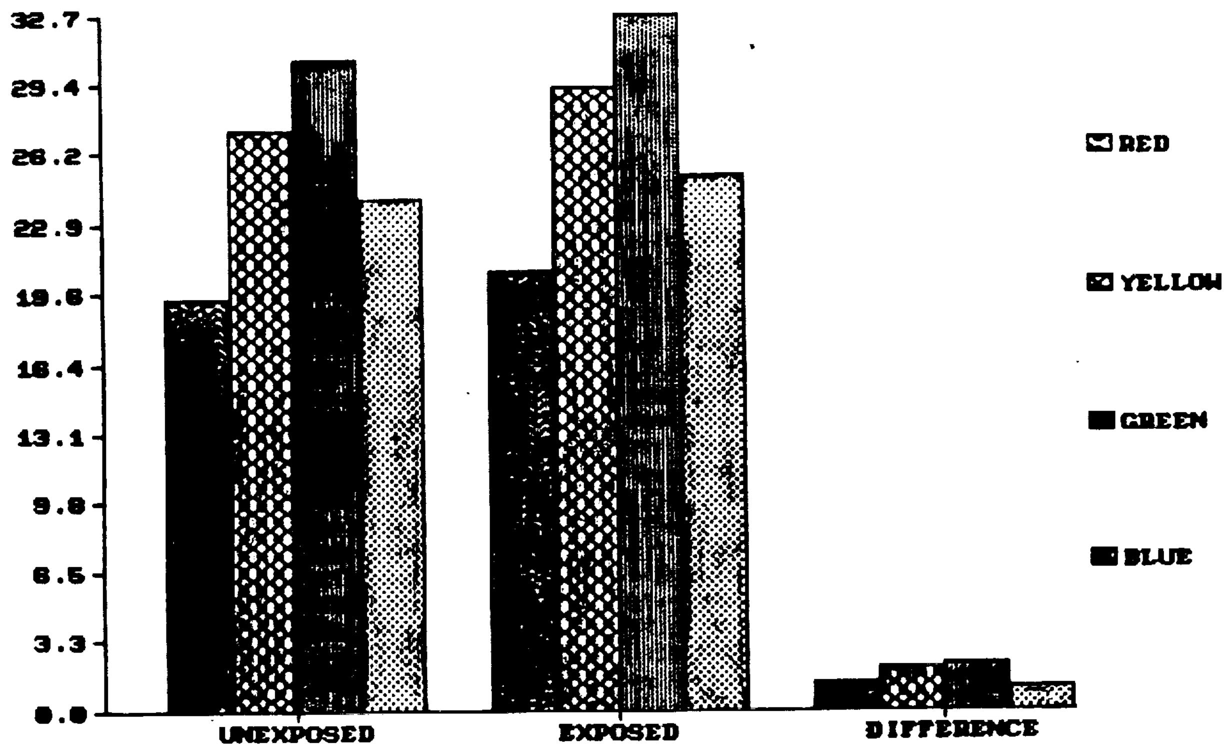


A0114 (3)

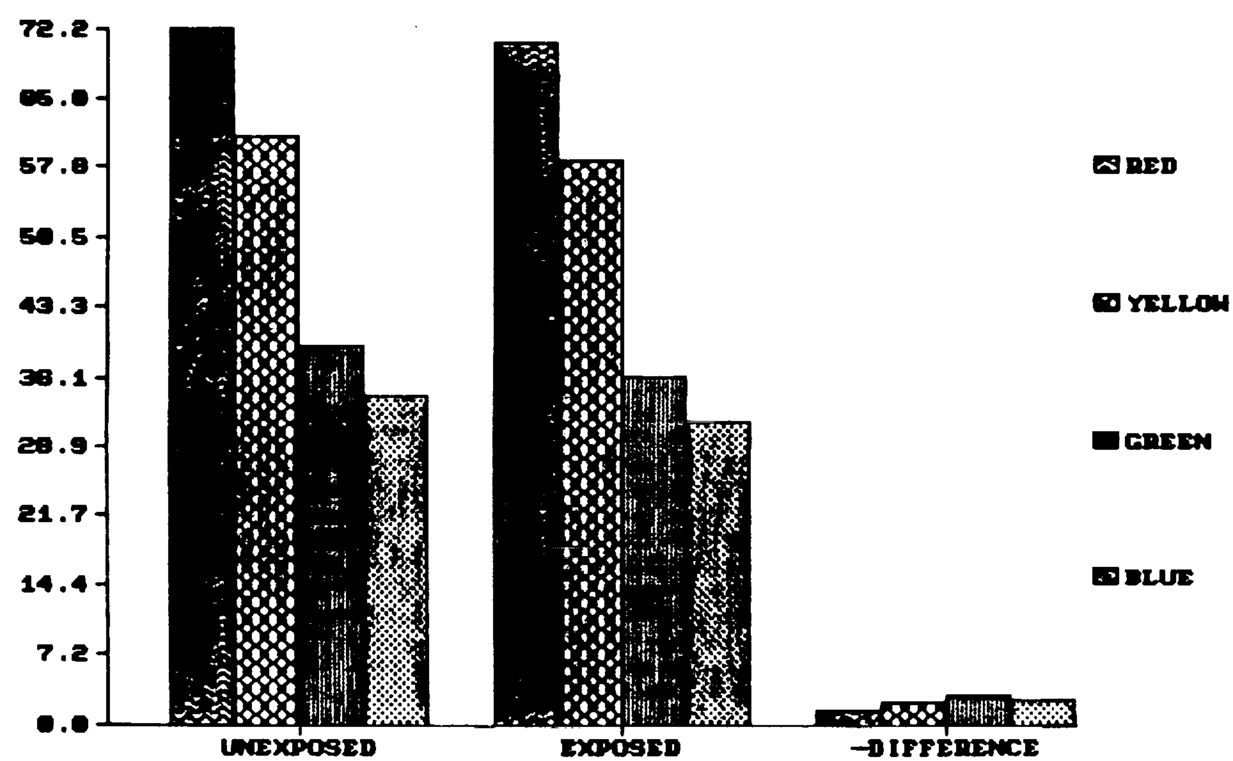
LDEF, A0114, C9-46, Au FILM, % REFLECTANCE



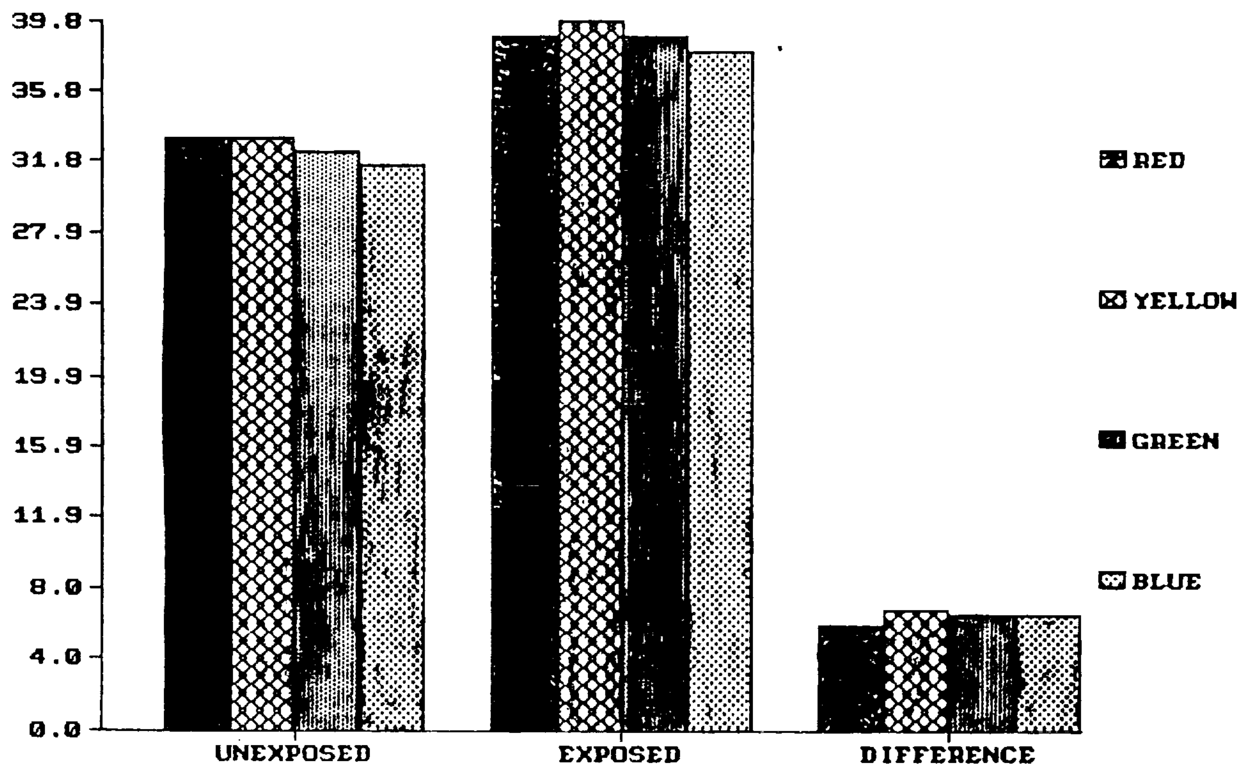
LDEF, A0114, C9-46, Au FILM, TRANSMITTANCE (PERCENT)



LDEF, A0114, C9-46, Au FILM, REFLECTANCE (PERCENT)



LDEF, A0114, C9-22, 100 A Nb Film, TRANSMITTANCE (%)



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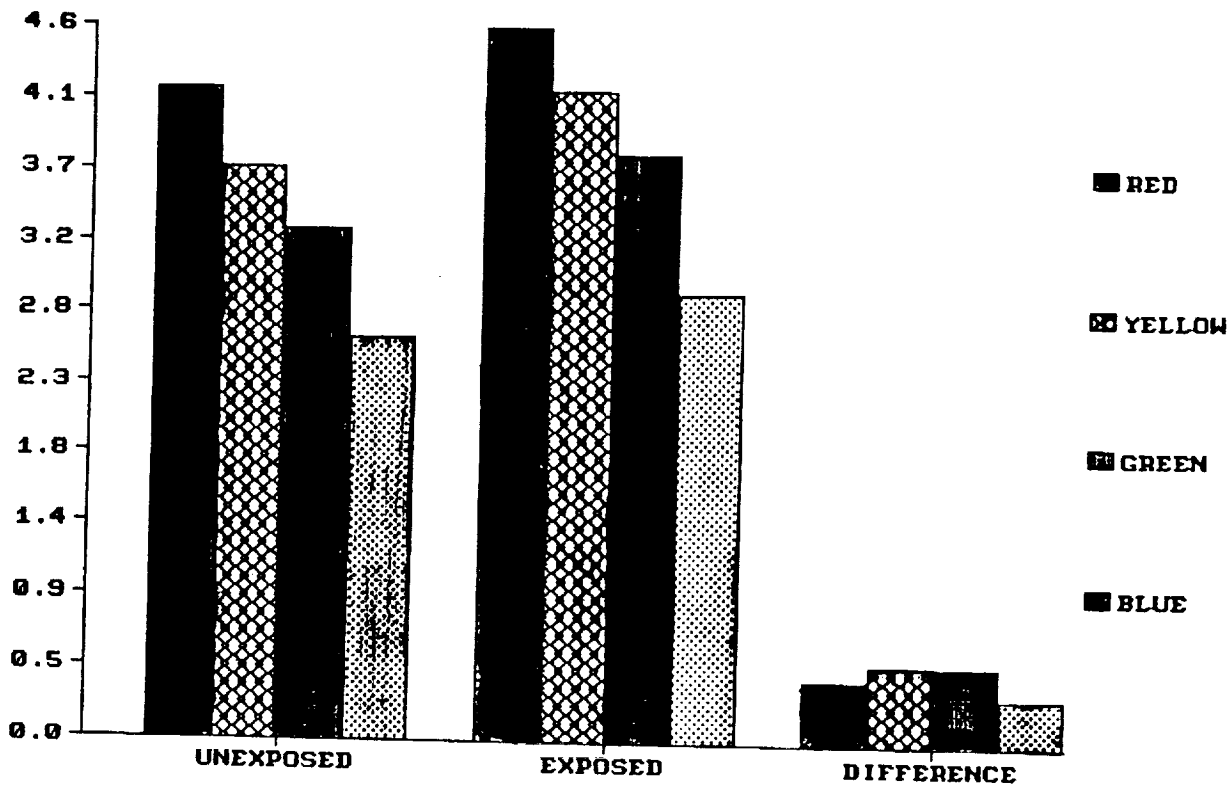
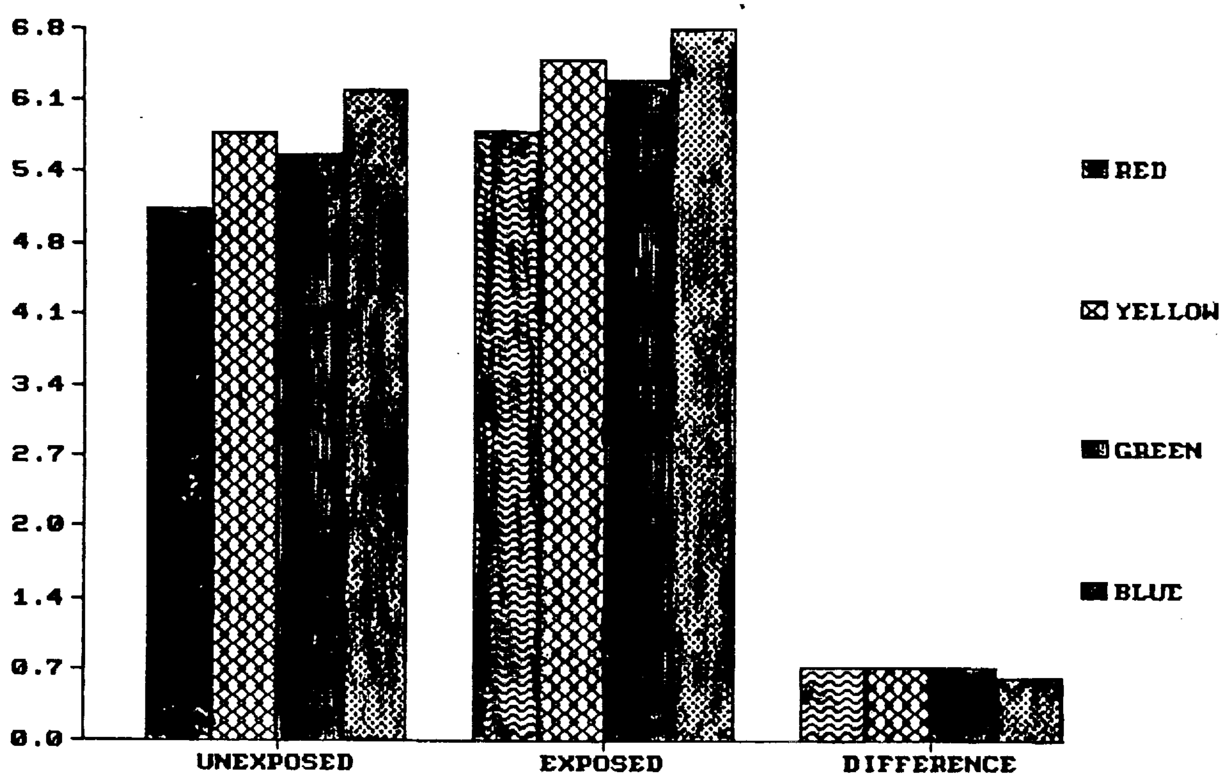
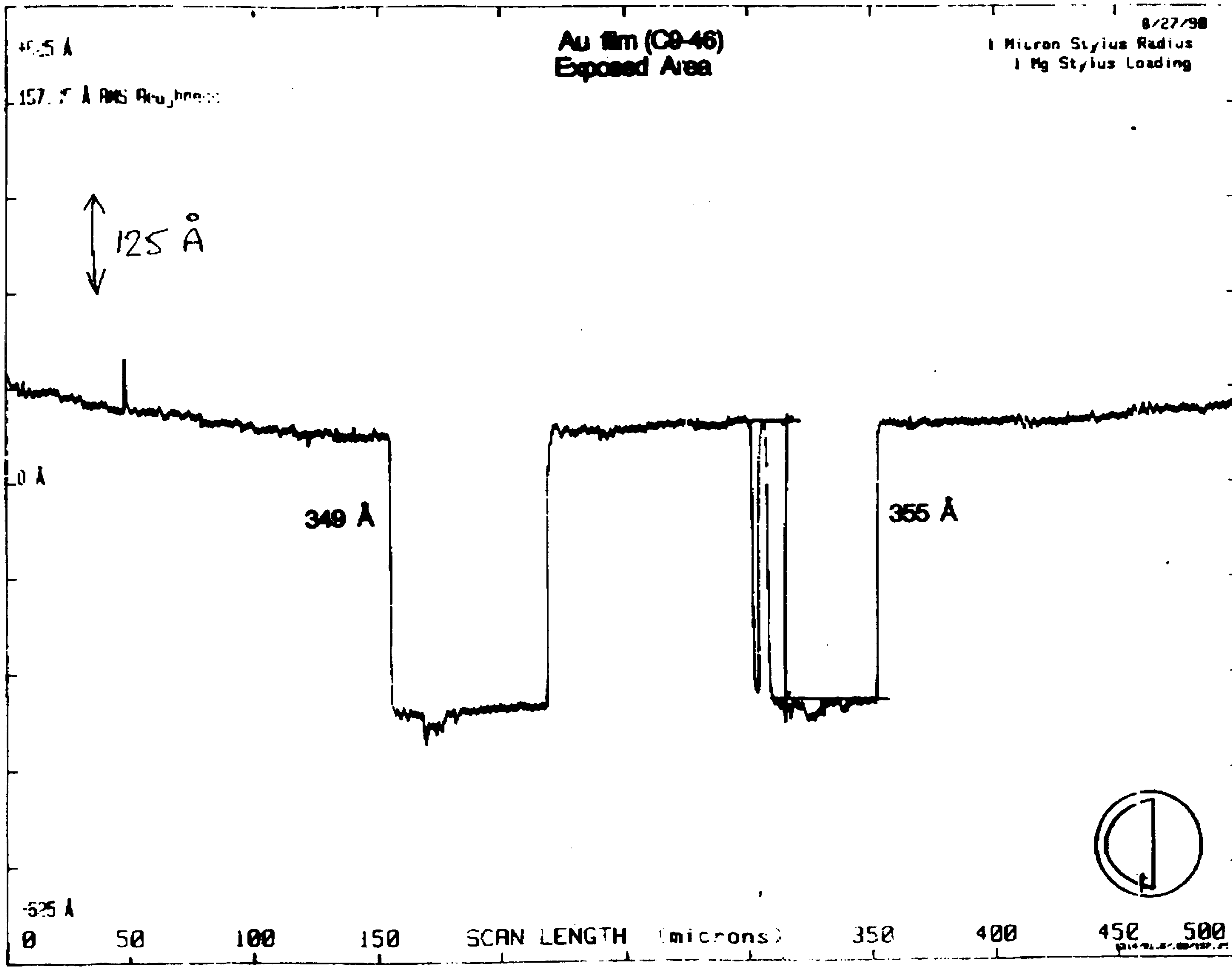
LDEF, A0114, C9-22, 800 A Nb Film, TRANSMITTANCE (%)



LDEF, A0114, C9-12, Ir FILM, TRANSMITTANCE (PERCENT)





Au film (C9-46)
Exposed Area
8/27/90
1 Micron Stylus Radius
1 Mg Stylus Loading
157. Å RMS Roughness
125 Å
0 Å
-525 Å
349 Å
355 Å
0
50
100
150
350
400
450
500
SCAN LENGTH (microns)

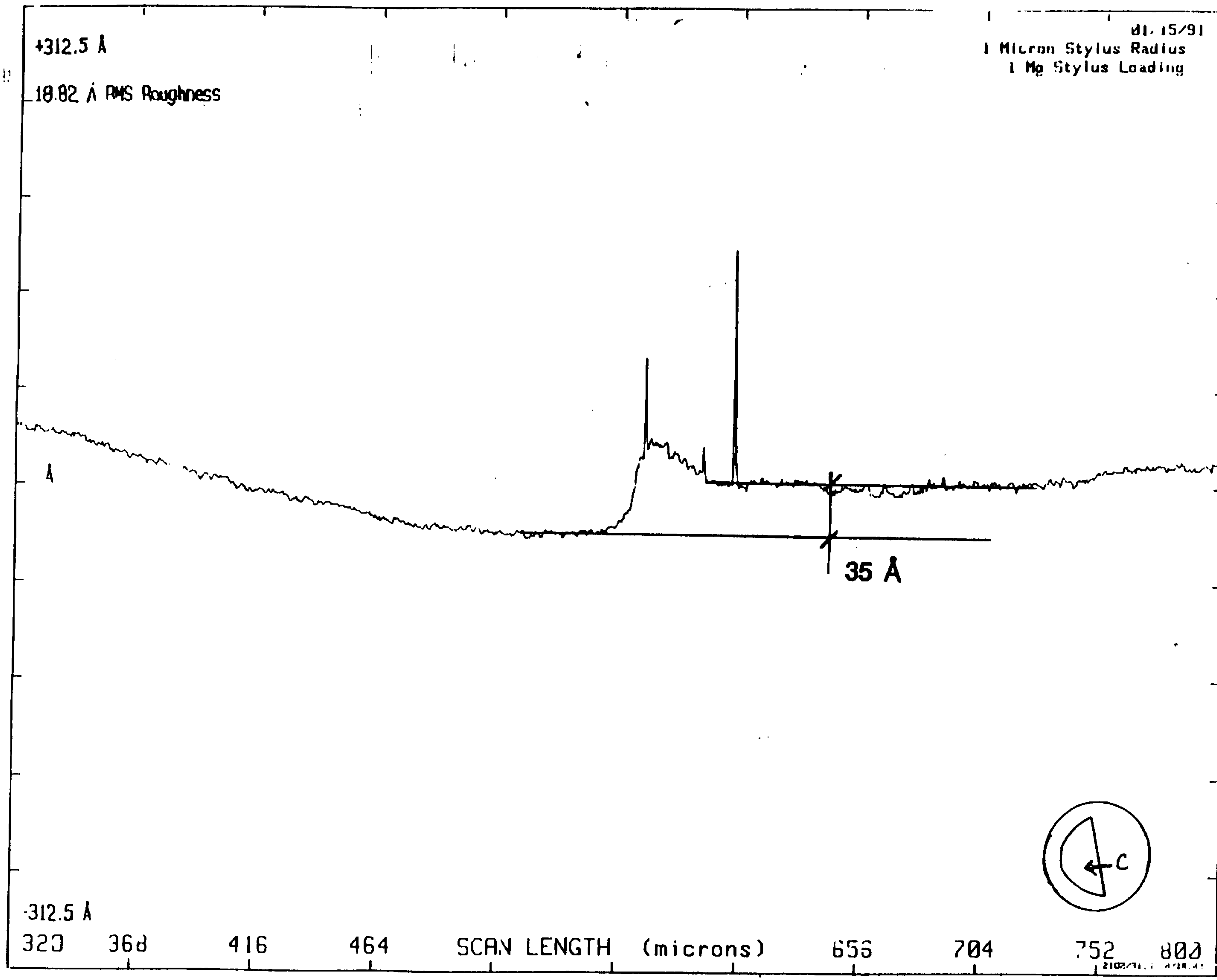
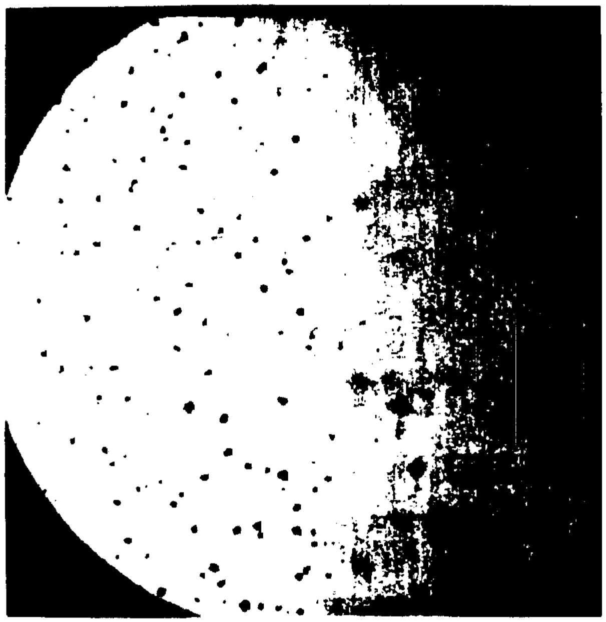
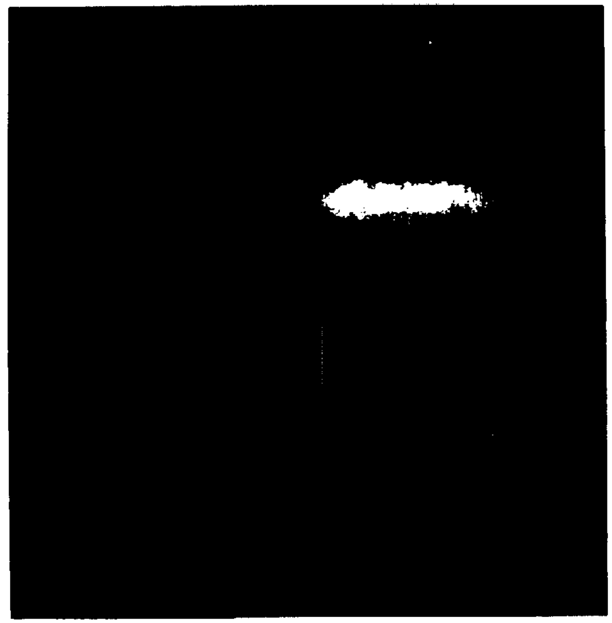


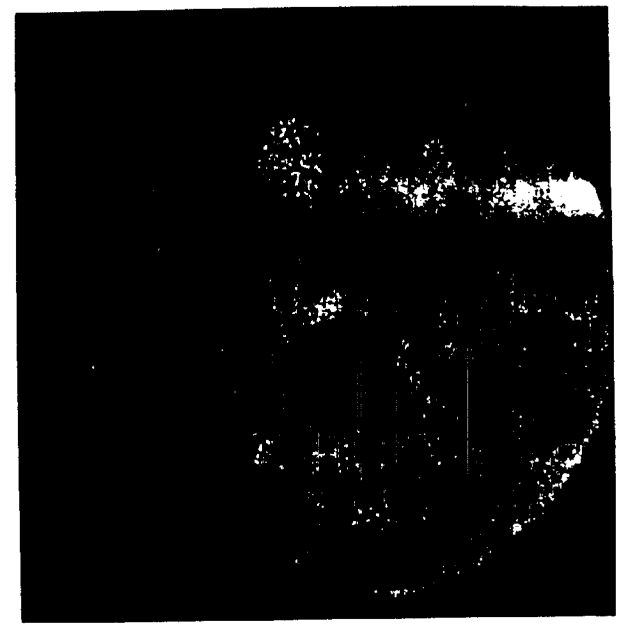
Figure 4.Surface profile of transition from unexposed to exposed ~~of~~ Iridium film



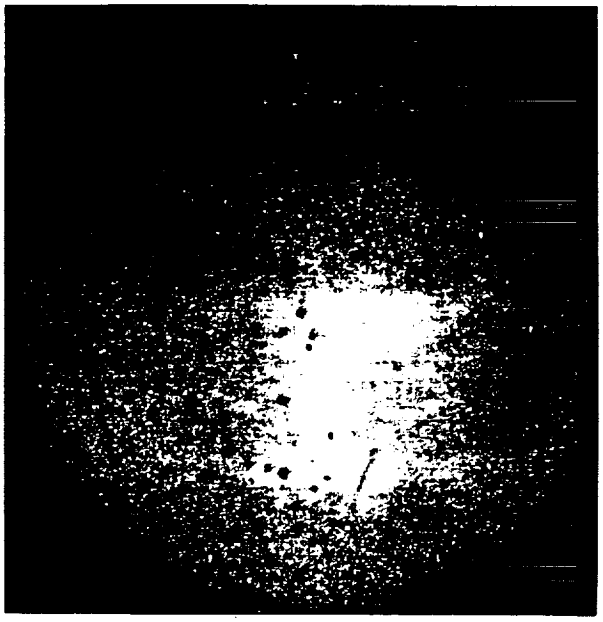
Ir Film, 11-15-91
Unexposed



LDEF, AO114, Ir Film, 11-15-91
~1 um lines (wide) in debonded structure in exposed area.

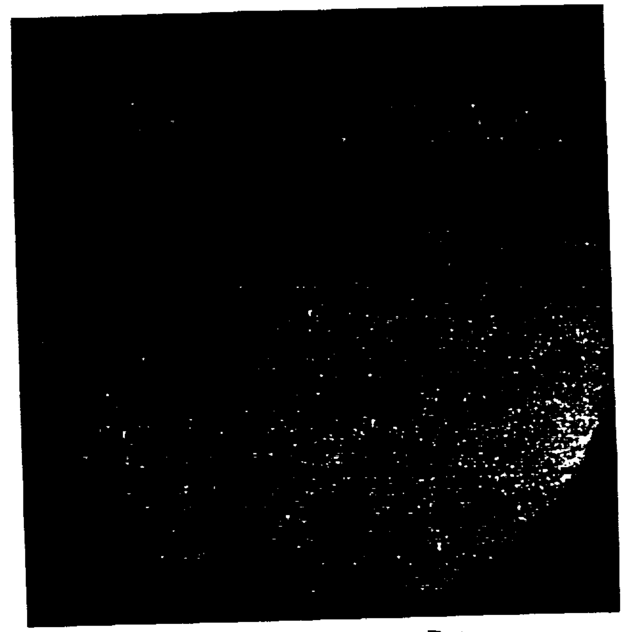


LDEF, AO114, Ir Film, 11-15-91
~1 um wide lines in debonded film in exposed area.



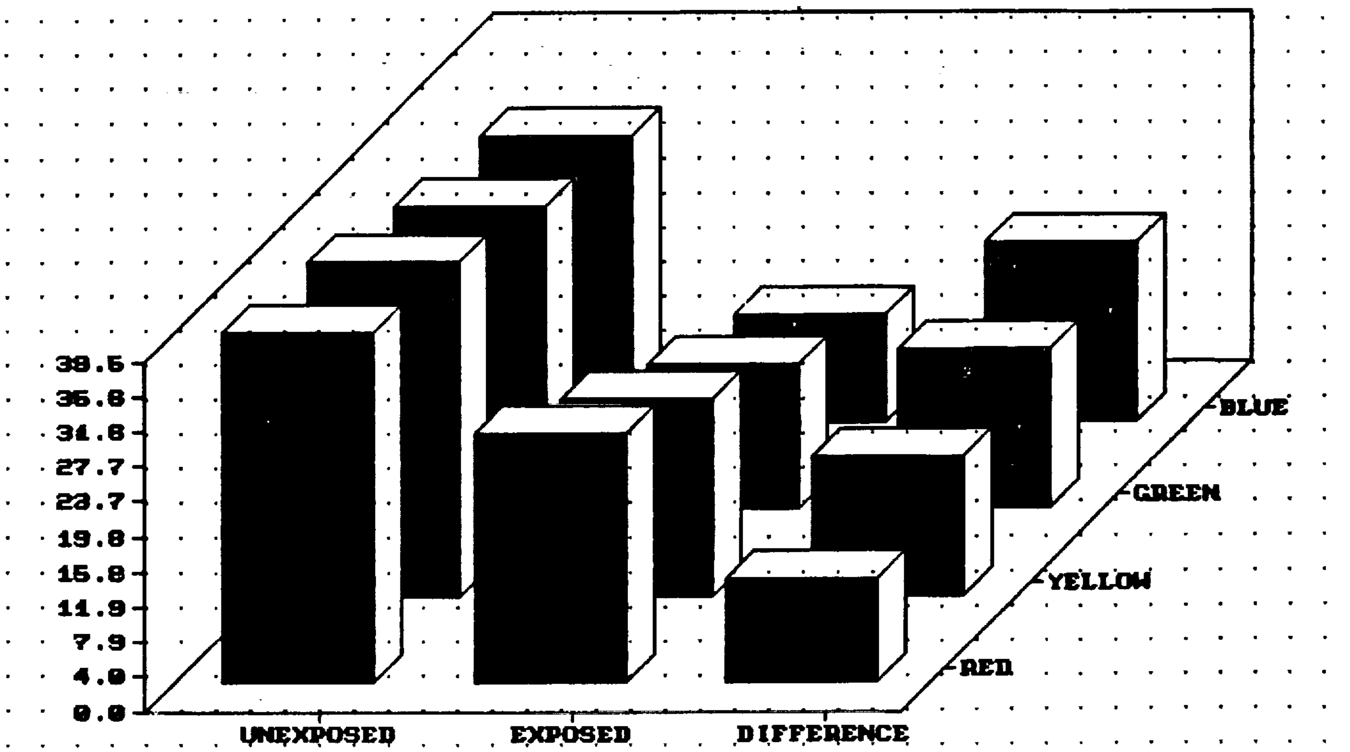
LDEF, A0114, Ir Film, 11-15-91

EXPOSED | UNEXPOSED



LDEF, A0114, Ir Film, 11-15-91
~1 μm wide lines in delaminated film in exposed area.

LDEF, A0114, C9-45, Ni FILM, REFLECTANCE (PERCENT)



LDEF, A0114, C9-45, Ni FILM, TRANSMITTANCE (PERCENT)